NACOE P120/ WARRIP-2021-016 Task 6A and 6B: Health and Environmental Effects of Incorporating Plastics in Binders and Asphalt

A JOINT INITIATIVE BY WARRIP AND NACOE

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Investigating the use of recycled and reclaimed plastic in safe, sustainable future road infrastructure

This report forms one element of a multi-stage research project undertaken as a joint initiative between the Western Australian Road Research and Innovation Program (WARRIP) and the National Asset Centre of Excellence (NACOE).

Stage 1 (2020–21) aimed to:

- review local and international projects that used recycled waste plastic in road and transport infrastructure
- identify the potential uses for recycled plastics in road construction and the relative quantities of materials that could be realistically used by each application
- review plastic waste streams in Queensland and Western Australia to understand market trends and capacity
- investigate workplace health and safety (WHS) requirements and environmental considerations associated with the use of waste plastics in road construction.

The publications completed under Stage 1 include:

- **Task 2–4: Investigating the use of recycled plastic in road infrastructure**
  - **2: Literature review**
  - **3: Plastic waste management (industry survey)**
  - **4: Workplace, health and safety, and environmental implications**

Stage 2 (2021–23) aimed to:

- explore safe and sustainable ways to expand the potential uses of waste plastics in transport infrastructure
- understand the health, safety and environmental impacts of using waste plastics in asphalt and bitumen, including microplastics, leaching, fuming and emissions.

The publications completed under Stage 2 include:

- **Task 5: Recycled plastics in infrastructure (Factsheet)**
- **Task 6: Health and environmental effects of incorporating plastics in binders and asphalt**
  - **6A: Laboratory fuming and emissions**
  - **6B: Microplastics and leaching**
- **Task 7: Potential use of recycled waste plastics in geosynthetics**
- **Task 8: Potential use of recycled waste plastics in temporary traffic management devices**

Summary

Recycled plastics are becoming one of the most talked about environmental issue in the world (Kumar & Singh 2019). There are plastics import bans enforced in the last few years from China and South-East Asian countries (Ellis-Petersen 2019), and national export bans are also now in place for some waste plastics (CSIRO 2021). Therefore, Australia has reached a precipice where there is a drive to internally spark change and promote circular economy principles and practices in order to manage the increasingly problematic issues of plastic stockpiles and divert them from landfill (CSIRO 2021).

The recycling of consumer waste plastics in roads as an additive or partial aggregate replacement has the potential to not only divert waste from landfill but also improve the properties of asphalt when compared to asphalt otherwise manufactured with unmodified bitumen. Currently, where asphalt pavements experience higher traffic loadings, specially produced polymers, such as styrene-butadiene-styrene (SBS) and ethylene-vinyl acetate (EVA), and repurposed crumb rubber, most commonly from truck tyres, are being used as additives successfully. For asphalt with lower traffic loading requirements, unmodified bitumen binders may be used. Questions about the impacts of using recycled waste plastics in bituminous binders and asphalt on the safety of people and the environment, however, have been raised.

Scope and Objectives

This project focused on assessing how the addition of selected consumer waste plastics may impact the fumes and emissions, microplastics and leachability of binders and asphalt. The fumes and emissions released during the preparation of binders and asphalt mixes containing recycled plastics as performed in the Australian Road Research Board (ARRB)/National Transport Research Organisation (NTRO) laboratory were examined and compared with those released during the processing of materials commonly accepted by the industry (unmodified bitumen, EVA-modified bitumen, and SBS-modified bitumen) and Safe Work Australia allowable exposure limits. For an accurate comparative study to be performed, fumes and emissions were measured during the blending of unmodified bitumen, conventional polymer-modified bitumen (SBS and EVA) and recycled-plastics-modified bitumen as well as during the preparation of their respective asphalt mixes. In all cases the specimens were manufactured and tested in a laboratory. The leachability of these binder blends and loose asphalt mixes (crushed and sieved) was also analysed and compared. A novel test methodology to measure the release of microplastics deriving from the corresponding asphalt mixtures to the environment was also developed and assessed.

The post-consumer recycled plastics used included a pelletised low density polyethylene (LDPE) from Western Australia, and a comingled high density polyethylene (HDPE) and polypropylene (PP) from Queensland. These plastics were readily available and represent common plastic types that derive as waste from consumer activities. The following materials were assessed as part of this research, including both binder blends and asphalt manufactured with those binders:

- unmodified C320 (binder and asphalt)
- C320/EVA (binder and asphalt)
- C320/SBS (binder and asphalt)
- C320/HDPE-PP (binder and asphalt)
- C320/HDPE-PP – dry method (asphalt)
- unmodified C170 (binder and asphalt)
- C170/EVA (binder and asphalt)
- C170/SBS (binder and asphalt)
- C170/HDPE-PP (binder and asphalt)
- C170/HDPE-PP – dry method (asphalt)

- C170/LDPE (binder and asphalt)
- C170/LDPE – dry method (asphalt).

This research is complementary to that by Austroads (2021a, 2021b, 2022a, 2022b). It was conducted to assess the repeatability of the proposed methods at different laboratories and assess the viability of additional different methods. It also included an investigation of leaching which was not considered in the research conducted by Austroads. It is noted that where Austroads terminology makes a distinction between the incorporation of relatively low melting temperature and higher melting temperature plastics with the aggregates during asphalt mixing as the mixed and dry methods, respectively, this report makes no such distinction. In this report, the incorporation of recycled plastics with the aggregates during asphalt mixing is referred to as the dry method, irrespective of the melting temperature of the plastics recycled.

The research aim was to develop a protocol to assess whether recycled polymers would be more hazardous to the exposed workers and the environment than commonly accepted practice, i.e. conventional materials. A safety protocol was developed along with specific recommendations for safe practice including the use of personal protective equipment, exposure time limits, and materials handling.

Fumes and Emissions

The quantification of fumes and emissions was undertaken in the laboratory environment using static and on-person samplers. Overall, it was found that even though in some cases the incorporation of recycled plastics (HDPE/PP and LDPE) resulted in an increase in the detected fumes and emissions when compared to the baseline materials (unmodified bitumen, EVA-modified bitumen, and SBS-modified bitumen), the measurements were well below the Safe Work Australia allowable limits.

In addition to the investigation of release of fumes and emissions in a laboratory environment undertaken to assess work health and safety effects, the project also investigated fumes and emissions from binders as measured in an enclosed test chamber, similar to the method presented by Austroads. The enclosed test chamber methodology was used as a conservative assessment of fumes and emissions, as the sampler was enclosed and relatively closer to the surface of the hot binders.

The analysis considered the quantification of released bitumen fumes, aldehydes, and total suspended particles as well as the polycyclic aromatic hydrocarbons (PAH) and volatile organic compounds (VOC). All analytes detected were at greatest concentrations emitted by conventionally accepted materials, except for formaldehyde, which was found to be emitted at the greatest concentrations by C170/LDPE followed by C170/HDPE-PP.

Microplastics

Assessing the impacts to the environment was found to be more complex, especially as in the case of microplastics, no maximum allowable limits have been established. For the assessment of microplastics, 2 different methods were investigated.

The investigation of microplastics considered not only the bitumen dissolution and density separation pathway assessed by Austroads, but also thermogravimetric analysis (TGA) as an alternative method. The trends observed by the quantification of released constituents following abrasion between the TGA used in this project and the method used by Austroads were found to be consistent, where the aggregates are the predominant matter released followed by bitumen and then microplastics. However, when the bitumen dissolution and binder separation method was followed, limitations relating to the method produced unexpected results. These were related to the selected solvents used for each of these steps as well as the selected filters. The approach that was followed considered solvents and equipment typically available in a bitumen laboratory.

TGA was found to be suitable for the quantification of microplastics, while a process of bitumen dissolution and density separation might be more appropriate for a study of their morphology, size and grade. From the TGA results, it was deduced that, with the exception of HDPE/PP incorporated via the dry method, the microplastics measured were comparable to that of asphalt manufactured with conventionally used polymers.

Leaching Potential

Two methods for the assessment of leachates were also employed. As there is no standard method for measuring leachates from binders and asphalt, a method to examine the leaching of the binders was developed using gas chromatography/mass spectroscopy (GC/MS) while leaching of the loose mix asphalt was assessed following methods commonly used for soils. For the assessment of the binders none of the analytes of interest were detected through GC/MS. It was, therefore, recommended that a more curated approach to the GC/MS method calibration is used in future. The results of the loose mix asphalt were found to be affected by the presence of the aggregates, especially in relation to the measurement of leachable metals. Therefore, a method where the particles were not crushed to size was further evaluated. These results were still found to potentially be affected by the presence of aggregates, given the persistent presence of aluminium. Further research is recommended to continue development of an appropriate method to assess the leaching potential of plastics-modified asphalt.

Key Outcomes

Overall, this research has benchmarked 2 common types of post-consumer waste plastics against conventional binder and asphalt materials used in Queensland and Western Australia.

The fuming and emissions assessment determined that the recycled plastics-modified samples were comparable to conventional bituminous materials in most cases. While an increase was seen from the recycled plastics-modified samples in some select instances, all results were well below Safe Work Australia exposure limits or limits recommended by the Australian Institute of Occupational Hygienists.

To quantify the potential for microplastics released to the environment, a specialised assessment methodology was developed. These results demonstrated that the content of microplastics released from recycled plastics-modified samples were comparable to those of conventional polymer-modified asphalt materials, with the exception of HDPE/PP incorporated via the dry method.

Finally, to understand the leaching potential of recycled plastics-modified samples, standard Australian methods for soil leachability were used, as well as a novel protocol. Further work has been recommended to continue assessing these leachability impacts.

Acknowledgements

The authors would like to acknowledge AMCOSH and specifically Robert Golec for the fumes and emissions measurements and results. The authors would also like to extend their appreciation to Dr Alex Duan and Dr Yukie O'Bryan for their support with TGA and GC/MS, work that was performed in part at the Trace Analysis for Chemical, Earth and Environmental Sciences (TrACEES) Platform at the University of Melbourne.

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List of Abbreviations

Abbreviation	***Definition***
ABS	Acrylonitrile butadiene styrene
AMAT	Accelerated microplastic abrasion test
ARRB	Australian Road Research Board
ATD	Automated thermal desorption
BF	Bitumen fumes
BPA	Bisphenol-A
CFC	Close-face-cassette
CO	Carbon monoxide
CRMB	Crumb rubber modified bitumen
CTPV	Coal tar pitch volatiles
EVA	Ethylene-vinyl acetate
FID	Flame ionisation detector
FTIR	Fourier-transform infrared spectroscopy
GC/MS	Gas chromatography/mass spectroscopy
HDPE	High-density polyethylene
LDIR	Laser direct infrared
LDPE	Low-density polyethylene
LLDPE	Linear low-density polyethylene
NO_x	Nitrogen oxides
PA	Polyamide
PAH	Polycyclic aromatic hydrocarbons
PET	Polyethylene terephthalate
PMB	Polymer modified bitumen
PP	Polypropylene

PPE	Personal protective equipment
PVC	Polyvinyl chloride
SBS	Styrene-butadiene-styrene
SEM	Scanning electron microscopy
TGA	Thermogravimetric analysis
TOC	Total organic compounds
TPM	Total particulate matter
TSP	Total suspended particles
TWA	Total-weighted average
UV	Ultraviolet
VOC	Volatile organic compounds

1 Introduction

1.1 Background

In 2019, the Council of Australian Governments was set to establish a timetable to ban the export of waste tyres, paper, glass, and plastic to build Australia’s capacity to generate high value recycled commodities (Department of Climate Change, Energy, the Environment and Water 2021). As a result, Australian government agencies and industry alike are seeking to find value-adding solutions for the generated plastic waste, among others. The view is that such solutions will have a positive environmental and economic impact (ARRB 2022).

One such area of interest is horizontal transport infrastructure, mainly due to its capacity to absorb large quantities, given that the road network exceeds 800,000 km (ARRB 2022). The use of recycled plastics in road infrastructure requires, for each application or product, an understanding of its impacts on engineering performance and any risks such use may introduce to the environment and human health. From reviewing literature, consulting with regulators, and engaging a suitably qualified person (SQP) it became evident that to recycle plastics into road infrastructure safely and responsibly, a risk-based approach was appropriate. The SQP report is provided in Appendix A. This research report presents areas which need to be considered to establish a risk-based approach to assess work health and safety (WH&S) and environmental implications of using recycled plastics in road infrastructure.

1.2 Project Scope and Objectives

This research project focuses on the WH&S and environmental impacts of incorporating recycled plastics in asphalt via both the wet and dry (hybrid) method. Workers are expected to be exposed to fumes and emissions during the processing of bitumen and plastics at elevated temperatures during binder blending and asphalt mixing as well as during road manufacture. Within the scope of this research project is the evaluation of fumes and emissions for benchmarking and in a laboratory environment where exposure is expected to be comparatively greater. It needs to be noted, however, that field measurements need to be considered separately and benchmarked against Safe Work Australia recommended upper limits of exposure. To understand the possible environmental impacts, the potential of recycled-plastics-modified asphalt to release microplastics and leachates to the aquatic environment needs to be understood.

Currently, there is no protocol for the assessment of these potential risks to the human health and the environment. Therefore, the aim of this research project is to develop a testing protocol for the quantification of fumes and emissions in the laboratory and leachates and microplastics to the aquatic environment. In addition, should it be found necessary, an updated safety protocol is to be developed.

1.3 Structure of the Report

Following this introductory Section 1, Section 2 summarises the literature that discusses the quantification of fumes and emissions and microplastics.

Section 3 describes the assessment protocol for fumes and emissions released in the laboratory during binder blending and asphalt mixing activities. The assessments were undertaken using static samplers placed where materials were processed; in-person samplers were placed in the breathing zone of the operators, and measurements in an enclosed test chamber were obtained for binder blending. The methods used for sampling were as follows:

- volatile organic compounds: NIOSH Method 1500, NIOSH Method 1501, AS 2986.1
- polycyclic aromatic hydrocarbons: NIOSH Method 5800
- aldehydes: NIOSH Method 2018
- total particulates and bitumen fumes: NIOSH Method 5040.

In Section 4, the methodology developed to measure the content of microplastics released through the abrasion of asphalt containing plastics-modified bitumen is described in detail and evaluated. Additionally, the leachability of the binders is evaluated using gas chromatography/mass spectroscopy (GC/MS) following a method similar to that proposed by White (2019) and of crushed and uncrushed loose asphalt mix following a standard method commonly used for the quantification of leachates in soils (AS 4439.2 and AS 4439.3).

The methods and results of the report are structured in 2 parts for both Sections 3 and 4. Part A outlines preliminary investigations and Part B reports the methods, materials, and results of the selected materials for use with the developed methodology. The conclusion of Section 5 summarises the findings and provides recommendations for adoption and further research.

The report also contains appendices as follows:

- Appendix A includes the initial SQP report from which advice was taken to formulate the content of the project.
- Appendix B includes the report provided by AMCOSH, who professionally collected static, in-person, and ambient measurements of the fumes and emissions released during the binder blending and asphalt mixing processes.
- Appendix C provides the SQP feedback on the proposed assessment frameworks of Part A of the experimental work.
- Appendix D includes the report from ASL who assessed leachates from the loose asphalt mixes following a method suitable for soils.
- Appendix E includes the material certificate proving the compliance of the C320 and C170 bitumen used as the base for all investigated binders.
- Appendix F summarises the preliminary proof-of-concept assessments that further advised the development of the assessment protocols of Task 6A (Section 3) and Task 6B (Section 4).
- Appendix G provides a summary of the proposed protocols for assessment for fumes and emissions, leachates, and microplastics.

2 Literature Review

2.1 Fumes and Emissions

During the production of asphalt, bitumen is processed at elevated temperatures releasing fumes such as sulphur, volatile organic compounds (VOCs), nitrogen oxides (NOx), carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAHs), and particulates. These have all been found to be harmful to the health of exposed workers (Borinelli et al. 2020) causing bronchitis and other respiratory symptoms (Burstyn et al. 2000). Deygout and Southern (2012) recognised that there are no international standards to measure the exposure of workers to those fumes, which has resulted in various methods being used producing results that may not be directly comparable. Additionally, factors such as processing temperature, bitumen composition, as determined by the source of the crude oil and the refining process, application methods, and meteorological conditions may affect exposure levels (Burstyn et al. 2000). Common methods for sampling include closed-face cassettes (CFC) often 37 mm in diameter, flame ionisation detectors (FID), and automated thermal desorption (ATD) (Unwin et al. 2013).

As the processing of unmodified bitumen is a fundamental step in asphalt mixing, techniques to measure the fume emissions, such as headspace techniques in combination with gas chromatography/mass spectrometry (GC/MS), have been established and successfully used by the industry (Porot et al. 2020; Porot et al. 2016), however, a bitumen-specific exposure analytical method is yet to be developed. Other methods to quantify bitumen emissions may include gravimetric techniques, liquid chromatography, and infrared spectroscopy (Burstyn et al. 2000). Calzavara et al. (2003) recognised that based on the various definitions of inhalable matter, particles up to 100 µm in diameter may be considered. Hence, they proposed that the commonly used 37 mm CFC might not be suitable, as it would only collect particles up to 40 µm and a sampler like that developed by the Institute of Occupational Medicine in Scotland might be more appropriate. Despite the fact, because the latter was found to be more likely to detect non-asphalt organic particulates when the 2 were compared, it was concluded that the standard 37-mm cassette testing may still be preferable (Calzavara et al. 2003).

Binet et al. (2002) developed a novel bitumen fume generator and used CFC to measure the total particulate matter (TPM) (otherwise referred to as total suspended particles (TSP)) and benzo(a)pyrene. TPM measurements were conducted by measuring the weight of the filters before and after sampling and the analysis of benzo(a)pyrene was achieved by twice extracting the filter in methanol in an ultrasonic bath. The extract was then injected into a liquid chromatographic system. PAHs and sulphur heterocycles were also identified through GC/MS. Gaudefroy et al. (2010) described the sampling of bitumen fumes when placed in a thermoregulated bath at 160 °C equipped with various probes to measure the total organic compounds (TOC) emitted. Sampling was conducted using portable automatic total hydrocarbon measuring equipment. The separation and evaluation of the fumes was achieved using a chromatography column and an FID. Repeatable sampling was demonstrated and other than the correlation of TOC emissions with temperature, an increase in emissions with an increase in stirring speed during the preparation of the bitumen was also found.

Several performance benefits have also been realised in the addition of specifically developed polymers in bitumen. These, however, increase the viscosity of the binder and so they require higher temperatures during mixing (Porot et al. 2020). Porot et al. (2020) used the stir bar sorptive extraction method combined with GC/MS to characterise VOC and PAH fumes deriving from polymer modified bitumen (PMB). They found that styrene-butadiene-styrene (SBS)-based PMB had lower VOC and PAH emissions than unmodified bitumen at any given temperature. This relationship was true even when the viscosity-based processing temperatures were considered.

Currently, the recycling of consumer plastics in asphalt is being investigated. For the successful adoption of such materials by the asphalt industry, a series of guidelines regarding the selection of appropriate polymers need to be considered, listing limitations regarding their recyclability which might affect performance, and the release of microplastics to the water stream need to be put in place (Austroads 2021a). Additionally, as derived from the SQP report in Appendix A, the leachability of the modified binders should also be investigated. Even though previous investigations have not reported concerning findings (White 2019), different additives may generate different results. Another consideration, like those discussed for unmodified bitumen, is the emission of fumes during the mixing process. At present, there are no guidelines in place advising acceptable emission limits and safe handling and monitoring during the processing of recycled plastics in bitumen. With the presence of polymers in the mixture at high temperatures, it is expected that other volatiles in addition to those present in unmodified bitumen might be present. Similar techniques such as those used for unmodified bitumen, namely GC/MS, FID, and ATD, have been used to measure emissions during polymer processing activities. The sampling strategy has been found to influence the data as different sampling methods provide different levels of sensitivity and is, therefore, to be carefully considered depending on the occupational exposure limits. In addition, it was noted that different manufacturing methods need to be considered separately as they may influence the type and quantity of microplastics released (Forrest et al. 1995). Thermoplastic polymers are being used in various manufacturing processes that involve high temperatures, like injection moulding, extrusion, and more recently additive manufacturing. It has been recognised that fumes during their processing at those elevated temperatures may be released. These depend on the grade of the polymer and the processing conditions (Unwin et al. 2013).

In this report, emissions deriving from the plastics mixing process with bitumen are measured. Several techniques have been developed for controlled emission and monitoring of such fumes; however, this research focuses on the measurement and monitoring of such fumes in a laboratory working environment. The aim is to develop safe handling and processing guidelines as well as an efficient sensor set-up configuration in a laboratory environment where plastics are mixed with bitumen at high concentration. Appropriate measures regarding the use of personal protective equipment (PPE) and exposure time and distance, among others, are proposed. In addition, a benchmarking method using an enclosed test chamber is also included to act as a comparative assessment tool between materials commonly accepted by the road construction industry and those containing recycled plastics.

2.2 Leachates and Microplastics

An additional consideration is the impact of such materials on the environment after exposure to ageing, weather, and traffic conditions. Exposure to the environment may also be considered when additives are introduced in bitumen.

Rainwater in contact with the asphalt as well as the spreading of asphalt particles abraded from the road surface may contaminate the surrounding soil and water. Therefore, such potential warrants investigation. It has previously been noted that the risk for leaching is dependent on the availability of contaminants for leaching rather than on their total concentration (Galvín et al. 2013). This can be determined by the Dutch Standard NEN 7341.

Brandt and De Groot (2001) assessed the PAH leaching potential of 9 different bitumens and an asphalt. They used a static leach test following European standard methods as closely as possible to measure the PAH leached by the bitumens and a dynamic leach test to assess a bitumen against asphalt. They found that both showed an increase in leachate concentration for the first 3 to 6 days, after which, they reached an equilibrium. This equilibrium was observed to stay well below the surface and potable water limits as set by European Economic Community countries. Birgisdottir et al. (2007) also investigated the leaching of PAHs from asphalt collected from 2 different locations and applications from the field using a tank leaching test based on the NEN 7345 standard. They found that only a minor portion of the PAHs contained in asphalt may leach to the environment (up to 1.1% for 5 PAHs) over the course of 25 years and noted that the PAH found in soil near roads was unlikely from the asphalt. It was agreed that leaching of PAHs is a diffusion-controlled mechanism (Birgisdottir et al. 2007; Brandt & De Groot 2001) and so diffusion calculations may be used for relevant calculations (Birgisdottir et al. 2007).

Xu and Zhang (2020) investigated the leaching potential for heavy metals of polyphosphoric-acid-modified bitumen under various conditions including different temperatures, different concentrations of sodium chloride, and acidic pH values (≤ 5.6) following a combination of the US EPA Method 1311 and 1312. Metals such as Cr, Cd, Ni, Cu, and Pb are typically present in crude oil products. They found that the addition of polyphosphoric acid did not aggravate the leaching of these metals.

It is also hypothesised that as friction with traffic tyres abrades the surface of the asphalt, particles from its surface are released. These could then make their way into the natural aquatic environment. It is understood that there is a risk of potential harm to the environment when plastics are used in road applications and should be considered prior to their wide adoption. As listed in Appendix A, these include microplastics that may lead to the environment and leaching of chemicals from those microplastics that may be released in the aquatic environment. Such environmental impact, however, has already been recognised as probable with the accepted fillers in bitumen (Rødland 2019; Vogelsang et al. 2020). Therefore, to evaluate whether the addition of recycled plastics has a more severe impact on the environment, a comparative study is conducted.

Masura et al. (2015) previously recognised the need to measure the content of microplastics in the aquatic environment and developed a laboratory method for their quantification. They used a sieve to collect contaminants smaller than 5 mm in diameter which they then separated into minerals and plastics using a density separation method through floatation. The plastics were then separated using an optical microscope and quantified through gravimetric methods.

2.3 Australian Research Context

In an extensive effort to understand the release of fumes and emissions as well as microplastics, Austroads carefully selected recycled plastics available in Australia and New Zealand and developed methods for their assessment. The plastics were shortlisted based on their characteristics, such as melt temperature and viscoelastic behaviour, and those deemed suitable were selected for further investigations (Austroads 2021a). A testing framework for the assessment of fumes and emissions as well as microplastics was developed (Austroads 2021b) and the results were presented (Austroads 2022a, 2022b). The sampling of fumes and emissions was undertaken using an enclosed flask at elevated temperatures where the binders were continuously agitated. The results revealed that the incorporation of plastics did not increase the concentration of VOCs and PAHs, rather the temperature was the predominant influencing factor (Austroads 2021b, 2022a, 2022b).

To investigate the potential release of microplastics, the asphalt surface was abraded, and the particulate matter was analysed following a multiple-step process. Firstly, the bitumen was dissolved and then the aggregates were separated from the plastics using density separation. The success of the process was qualified through optical microscopy, while gravimetric data were acquired at every step of the process to quantify the constitution of the abraded matter. It was found that the abraded matter decreased with an increase in the content of plastics. The type of plastic used was also an affecting factor (Austroads 2021b, 2022a, 2022b).

3 Task 6A: Operator Safety – Detailed Test Methodology for Laboratory Fumes and Emissions during Binder Blending and Asphalt Mixing

3.1 Part A: Preliminary Investigation

Measurements for air pollutants generated during the binder blending process and asphalt mixing processes of unmodified bitumen, SBS-modified bitumen, and ethylene-vinyl acetate (EVA)-modified bitumen, which are currently used in asphalt and sprayed seals in Australia, were undertaken to set the baseline of current practice exposure of laboratory operators to fumes and emissions. Measurements of fumes and emissions from the blending and mixing of recycled plastics were also taken and compared to the baseline. This was to investigate whether the incorporation of recycled high-density polyethylene/polypropylene (HDPE/PP) in asphalt is prohibitive due to safety concerns and generate advice for effective use of PPE.

AMCOSH provided advice regarding the measuring locations and equipment required for the most efficient measuring. Measurements were taken within the ARRB laboratory where the mixing of binders and asphalt takes place in high concentrations and where, according to Burstyn et al. (2000), fume exposure is relatively high, simulating a worst-case scenario.

3.1.1 Materials

The unmodified bitumen used for this investigation was C320 as there exists a greater database of testing results on binders and mixtures of this grade. However, C170 bitumen would be a more common base binder for polymer modified mixes. The selected polymers for the baseline PMB mixture were SBS and EVA. Lastly, measurements during the blending of recycled consumer plastic (HDPE/PP) with the C320 bitumen were conducted to investigate whether the exposure effects are amplified and if so, develop a specific safety protocol for all those affected. These different mixtures are henceforth referred to by their sample ID, as listed in Table 3.1. All binder blending was undertaken at 4,000 rpm for 1 hour at 180 ± 10 °C. The asphalt was mixed at 160 ± 10 °C.

Table 3.1: Binder and asphalt naming convention and process parameters during the binder blending and asphalt mixing process

Sample ID	Additive	Content of additive (%)
Binder blending		
B-C320[1]	N/A	0
B-C320/EVA	EVA	6
B-C320/SBS	SBS	6 (+3 wt.% combining oil)
B-C320/HDPE-PP	HDPE-PP	6
Asphalt mixing		
A-C320/EVA	EVA	0.3
A-C320/SBS	SBS	0.3 (+0.15 wt.% combining oil)
A-C320/HDPE-PP (w)(2)	HDPE-PP	0.3
A-C320/HDPE-PP (d)(2)	HDPE-PP	5
A-C320	N/A	0

[1] B prefix indicating a binder sample while A prefix indicates asphalt.

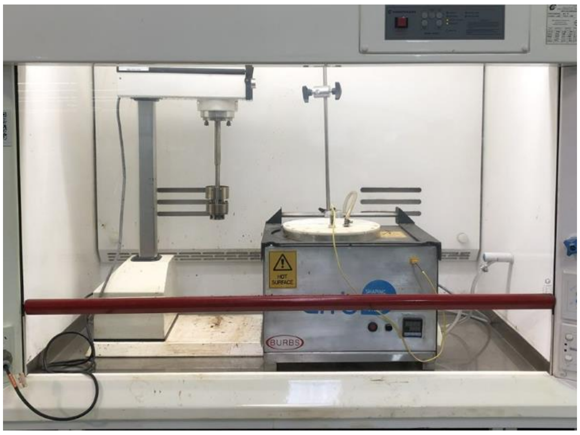
[2] (w) denoting asphalt mixed via the wet method and (d) denoting asphalt mixed via the dry method.

3.1.2 Binder Blending and Asphalt Mixing Process

Binder blending

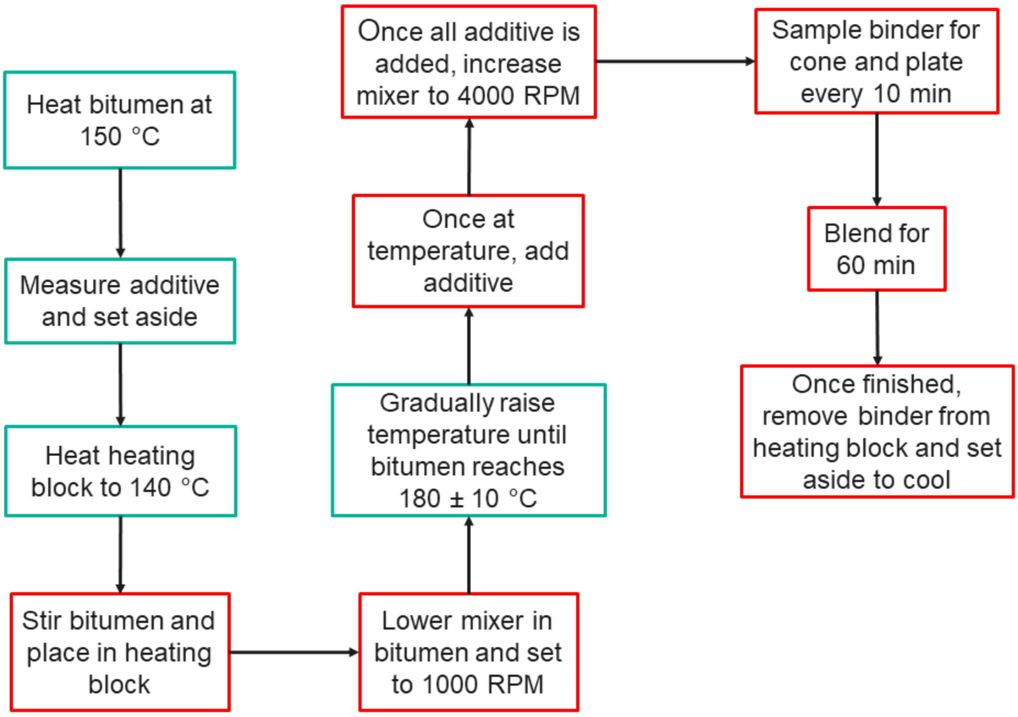
The binder preparation was achieved using a Silverson high shear mixer. The process involving the incorporation of additives in the bitumen is outlined in Figure 3.2. Of particular interest for the purpose of this research are the steps highlighted in red as they involve the probable exposure of the operator to fumes generated by the binder mix. It needs to be recognised that in the ARRB laboratory the mixing would take place in an enclosed chamber, called the heating block, under CO_2 atmosphere, all within an extraction fume hood, as per Figure 3.1.

Figure 3.1: Blending set-up in ARRB laboratory



In addition, the laboratory operator preparing the blend wears PPE including a face shield, safety boots, lab coat, safety glasses, and heat resistant gloves. Outside of ARRB, common practice would be for the mixing to take place in ambient atmosphere, on a hotplate, possibly under a fume hood. Therefore, for the purposes of this research, the CO_2 gas was turned off for a wider representation of laboratory processes across Australia. The quality of the binder mix is recommended to be checked every 10 minutes to ensure that undesired events, such as air entrapment, blockages, and foaming, are not taking place. This step is of particular concern because the temperature of the binder during blending is set to 180 ± 10 °C, where the emission of volatiles, like alkanes, are comparatively high (Borinelli et al. 2020).

Figure 3.2: Plastics modified binder preparation using the wet process



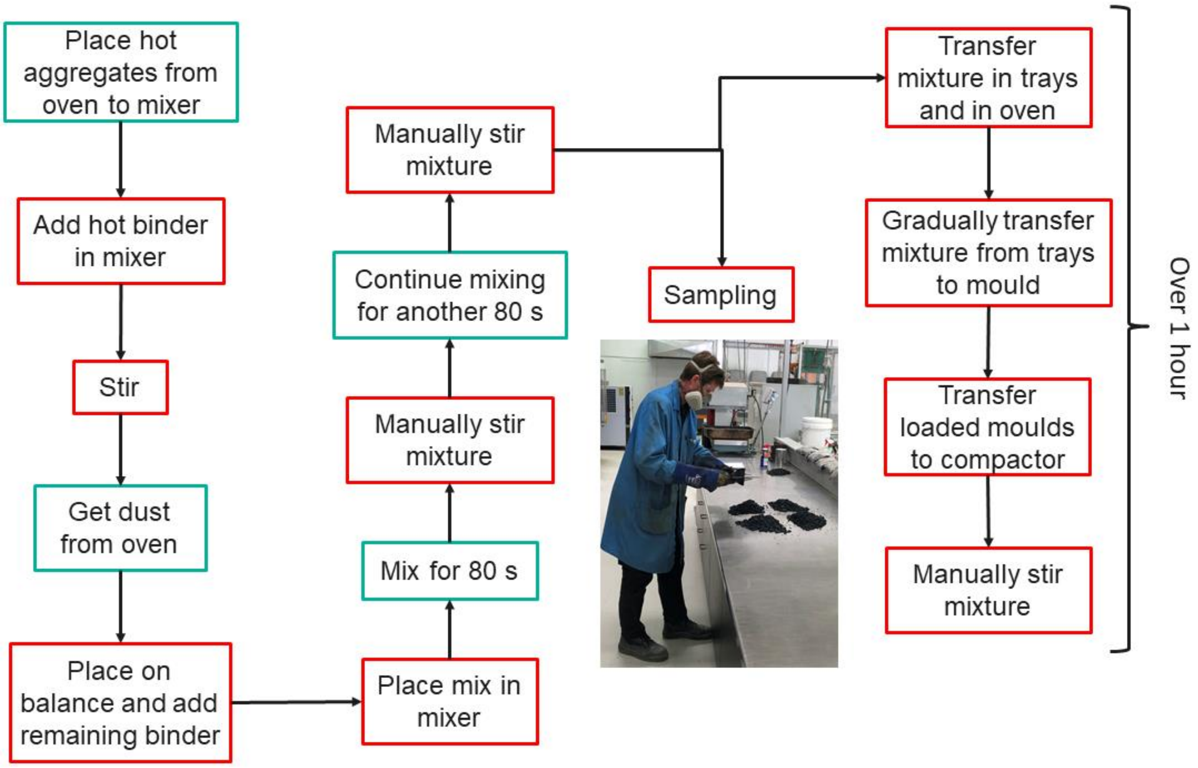
Note: Actions in red indicate operator exposure to binders at high temperature.

Asphalt mixing

The asphalt sample preparation, sampling, and compaction were performed according to AS/NZS 2891.1.1:2013, 2891.2.1:2014, and 2891.5:2015, respectively. Of particular interest were the steps that involved high temperatures highlighted in red in Figure 3.3. Specifically, other than the conditioning step where the binder is placed in an oven covered with a lid, where minimal exposure is expected, the mixing of the binder with the aggregates, the temperature measurement steps, the collection of samples, and that of compaction were of interest. Even though not applicable for the laboratory at ARRB, measuring the emissions during the flash point test should also be considered. CO_2, CO, and non-methane gaseous organic compounds may be detected during this process (Jullien et al. 2010). During hot asphalt mixing, all parts are conditioned at elevated temperatures (150 °C) in air forced ovens.

When mixing is complete, several manual handling operations take place for sampling and compaction. These take place while the asphalt is still hot and, therefore, there is an elevated risk of exposure to volatiles. Hot asphalt mix is placed in trays and gradually transitioned in heated moulds and those are further conditioned in the oven at 150 °C. This process is completed within the span of 1 h. The monitoring of the temperature in the centre of the mix is important and, therefore, during that time the oven is opened frequently while the operator remains in the area performing other tasks, such as sampling and cleaning, for the duration. This process is illustrated in Figure 3.3, where areas of concern are highlighted in red. An additional space of concern is during the transportation of hot asphalt mixes to the compactors.

Figure 3.3: Hot asphalt mixing, sampling, and compaction process



Note: Actions in red indicate operator exposure to binders at high temperature.

It needs to be noted that during the monitoring of fumes and emissions other actions need to be halted so that cross-contamination of the samples is avoided. Similar concerns were raised by Calzavara et al. (2003) who recognised that certain false positives may be detected due to non-asphalt airborne organic particulates.

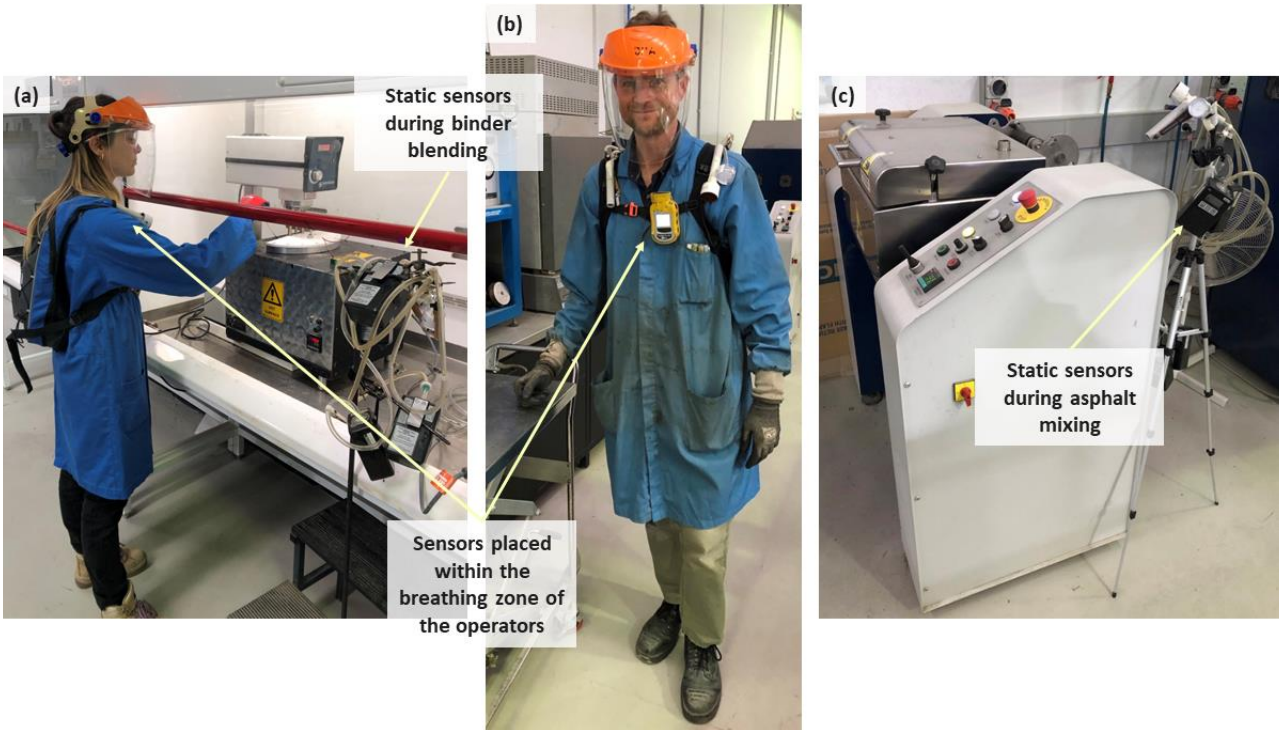
3.1.3 Proposed Sampling Protocol

Measurements were taken for TSPs, bitumen fumes (BF) (otherwise referred to as coal tar pitch volatiles (CTPV)), PAHs, VOCs, and aldehydes in static locations in the binder blending and asphalt mixing and compaction areas as well as from the operator's breathing zone during the full duration of the processes. The measurement procedure is summarised below, while more details are provided in Appendix B.

Location for efficient measurement

Processes such as binder blending and hot asphalt mixing, where the components of asphalt are handled at elevated temperatures, were taken into consideration. The asphalt mixing process took place under ambient atmosphere while the binder blending took place under a fume hood. The ARRB laboratory is equipped for both the preparation of bitumen and the hot mixing of asphalt. Both processes were assessed for all different materials. Data was collected from both static sensors and sensors placed in the breathing zone of the operator, as shown in Figure 3.4. During the process of asphalt mixing, the static sensors were moved following the locations where the materials were handled. The monitoring locations were selected to represent the exposure of a laboratory operator undertaking these actions as well as risk to others operating within the same area.

Figure 3.4: Sensor placement during fumes and emissions monitoring: (a) binder blending set-up with static and within breathing zone sensors, (b) sensor set-up for monitoring fumes and emissions within the breathing zone of the operator, and (c) static sensors during asphalt mixing

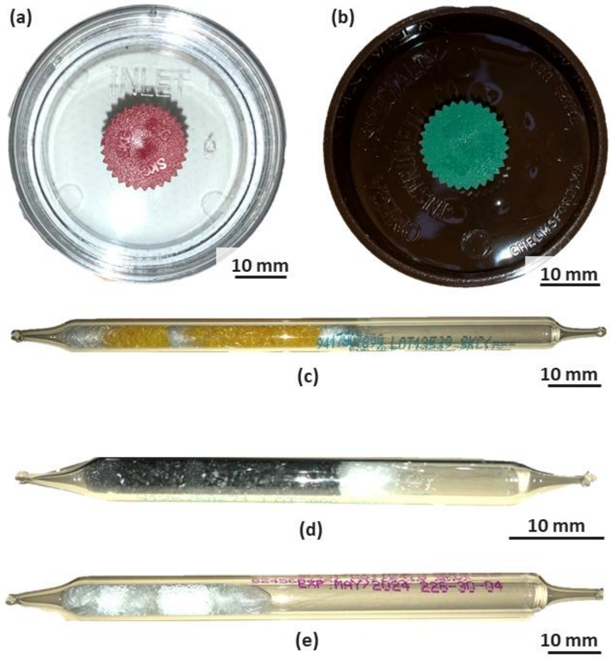


These measurements represent laboratory conditions and other steps of the process are not covered. The emissions during asphalt mixing in manufacturing plants have previously been considered by the National Pollutant Inventory (1999) for all different plants, namely batch mix plants and parallel and counter flow drum mix plants. It was proposed that most of the emissions in those plants are the result of supplementary processes, such as fuel combustion. Another concern in manufacturing plants is the inhalation of particulate matter as a product of grinding, breaking, and crushing operations (National Pollutant Inventory 1999). Zanetti et al. (2014) focused on measurements on the point of laying. These steps are not within the scope of this study, which investigates laboratory exposure.

Sampling devices and methods

It is recognised that the measurement devices selected during the measuring and monitoring process can affect the quality of the collected data. This is because they have been reported to have different efficiencies and are often targeted depending on the type of emissions that are to be measured. The sampling devices employed in this study are depicted in Figure 3.5.

Figure 3.5: Fumes and emissions sampling devices: (a) CTPV (BF) sampling cassette, (b) semi-volatile PAH sampling PTFE cassette, (c) aldehydes sampling 2,4-dinitropheylhydrazone treated silica gel tube, (d) VOC sorbent sampling tube (SKC Part Number 226-01), and (e) volatile PAH XAD-2 solid sorbent sampling tube



The sampling of VOCs was conducted in accordance with NIOSH Method 1500 (Hydrocarbons, BP 36°-126 °C), NIOSH Method 1501 (Hydrocarbons, Aromatic) and AS 2986.1:2003 at a flow rate of approximately 0.1 L/min. PAHs were sampled following NIOSH Method 5800 at a flow rate of 2.0–2.5 L/min while the NIOSH Method 2018 was used for the sampling of aldehydes at approximately 0.5–1.0 L/min. Lastly, TSP and BF were sampled using NIOSH Method 5040 at a flow rate of 2.0–2.5 L/min. Details on the total concentrations of samples collected are provided in Appendix B.

Analysis methods

After sampling, all samples were refrigerated until they were sent for laboratory analysis as follows:

- For the quantification of VOCs, samples were analysed through GC/MS by the method of solvent desorption with carbon disulphide following Method WCA.2.07
  - the limit of reporting (LOR) for aromatic and aliphatic hydrocarbons by this method is 5 µg per sampling tube.
- GC/MS was also used for the analysis of PAHs by solvent desorption with an LOR of 0.1 µg per filter or sampling tube.
- Aldehydes were analysed through solvent extraction with acetonitrile and high-performance liquid chromatography (HPLC) with an LOR of 0.25 µg per tube.
- TSP and BF were analysed through gravimetry and solvent extraction using cyclohexane with 0.01 mg and 0.05 mg LOR per filter, respectively.

3.1.4 Results

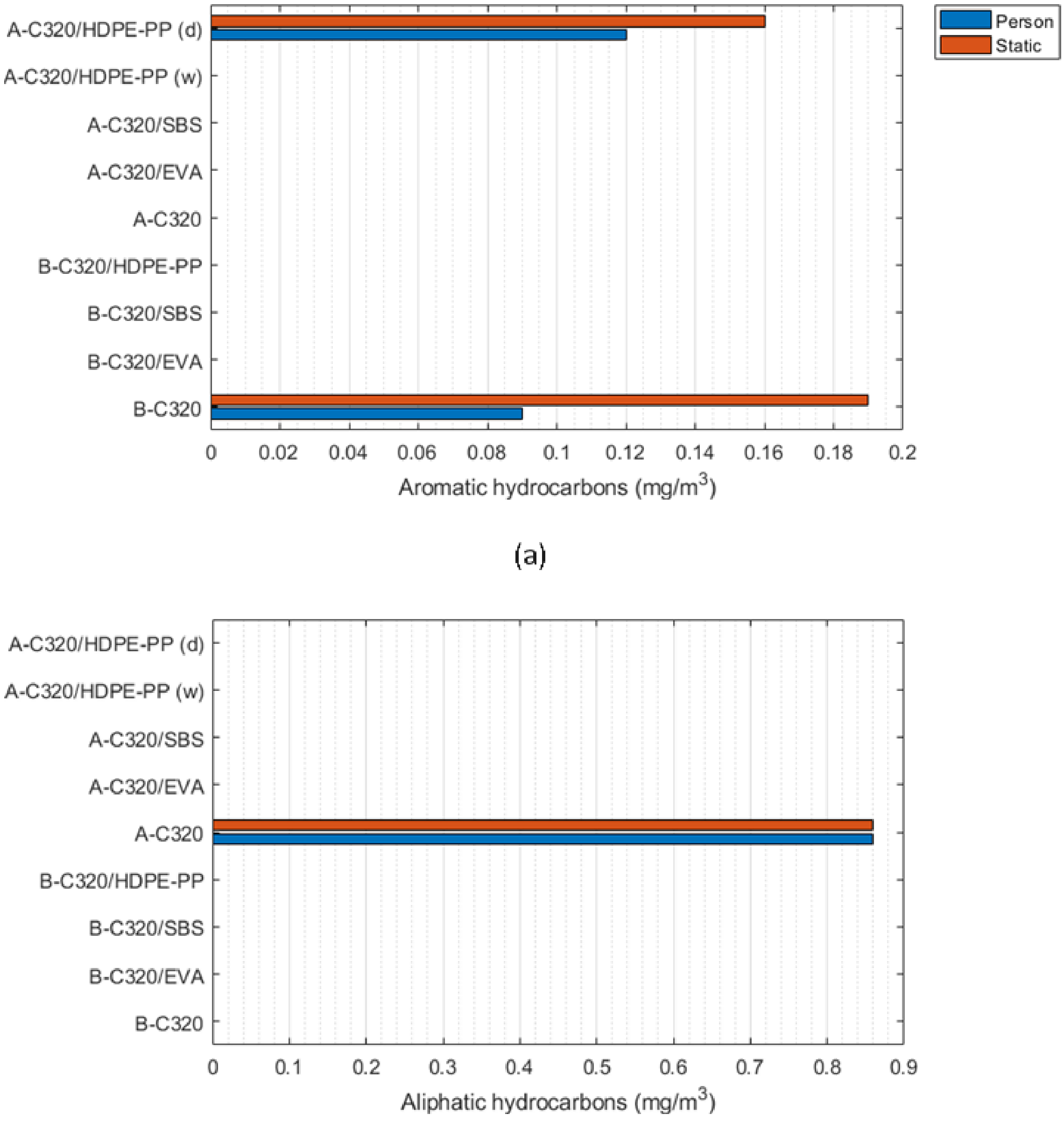
In this section, a summary of the measurements of the fumes and emissions as sampled within the operator’s breathing zone and by static measurements is provided. These are calculated based on time-weighted average (TWA), which refers to exposure in a 5-day work week assuming 8 hours of work per day. Further details are provided in Appendix B.

In Figure 3.6 to Figure 3.9, the measured fumes and emissions of the recycled plastic-modified samples are compared against the unmodified bitumen and conventional PMBs in both blending and asphalt mixing. Where the measurements were below the limit of quantification, no values are reported. It is recognised here that blending of unmodified bitumen is not something required during common practice but was conducted for the purposes of the comparative analysis.

Volatile organic compounds

The measured VOCs are presented in Figure 3.6. Both polymers and bitumen are susceptible to the release of VOCs during exposure to elevated temperatures, such as during binder blending and asphalt mixing. Overall, all measured VOCs were found to be well below the recommended exposure upper limit set by Safe Work Australia (2013).

Figure 3.6: Total VOCs detected during binder blending and asphalt mixing on the operator's person and static samplers: (a) aliphatic hydrocarbons and (b) aromatic hydrocarbons; LOR for VOCs is 5 µg per sampling tube and TWA for total VOCs (aliphatic and aromatic hydrocarbons) is 790 mg/m^3



(a)

(b)

When considering the release of aromatic hydrocarbons in Figure 3.6 (a) during binder blending, unmodified bitumen (B-C320) was the only one to release aromatic hydrocarbons as measured by both the static and in-person samplers. These were only comprised by toluene, and they represented 0.05% of the workplace exposure standard (TWA = 191 mg/m^3). Toluene was also the only aromatic hydrocarbon detected during asphalt mixing. Toluene was emitted only by the mixing of sample A-C320/HDPE-PP (d).

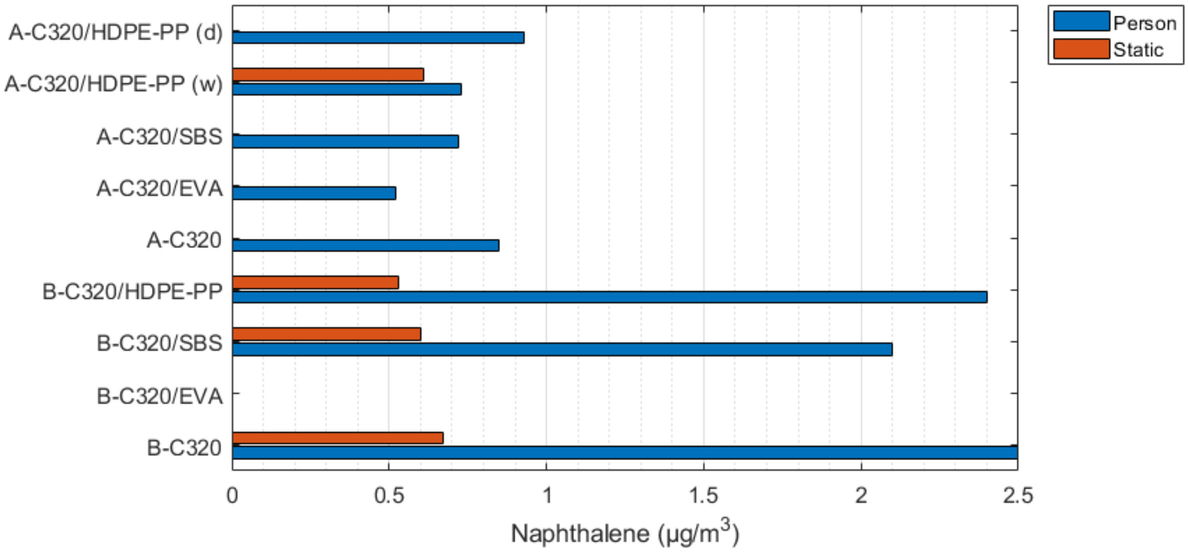
From Figure 3.6 (b), the aliphatic hydrocarbons were released only during the asphalt mixing of unmodified bitumen (A-C320). These were comprised of cyclopentane, cyclohexane, and hexanes (other than n-hexane and cyclohexane) in no more than 0.09% of the total allowable concentration for all 3 VOCs.

The only case where the incorporation of HDPE/PP was found to emit VOCs beyond the levels detected by the baseline materials was during the asphalt mixing through the dry process (Figure 3.6 (a)).

Polycyclic aromatic hydrocarbons

Figure 3.7 shows the concentration of naphthalene, which was the only PAH detected, for the in-person and static samplers. Safe Work Australia (2022) has set an upper limit for allowable exposure to naphthalene at 52 mg/m^3. The detected concentration of overall PAHs was found to be well below this allowable limit of exposure.

Figure 3.7: Total PAHs (naphthalene) detected during binder blending and asphalt mixing on the operator's person and static samplers; LOR for PAHs is 0.1 µg per sampling tube or filter and TWA for naphthalene is 52 mg/m^3



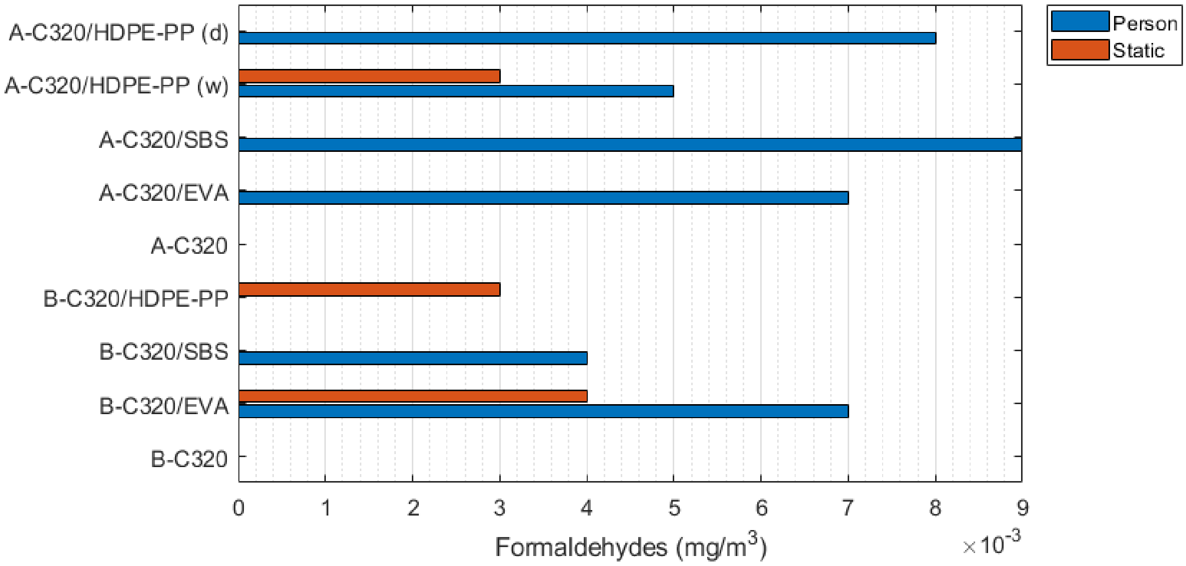
From Figure 3.7, the greatest concentration of naphthalene was detected within the breathing zone of the operator during binder blending of unmodified bitumen (B-C320) in a concentration level of 0.005% of the allowable Safe Work Australia limit. The static measurements during blending of unmodified bitumen were also the greatest among the other samples, but notably lower than those of the in-person levels. During asphalt mixing, however, the detected concentration of naphthalene within the operator's breathing zone when using unmodified bitumen (A-C320) is a close second to that measured during the asphalt mixing incorporating HDPE-PP through the dry method (A-C320/HDPE-PP (d)). Naphthalene detection levels from static measurements during the asphalt mixing were above the quantification limit only for sample A-C320/HDPE-PP (w). Importantly, neither benzo(a)pyrene, which is the most carcinogenically potent PAH, nor any of the other 14 priority PAHs were detected for any of the samples.

The incorporation of HDPE/PP resulted in greater emission of naphthalene for both in-person and static samplers during asphalt mixing during the dry and wet method, respectively.

Aldehydes

Figure 3.8 shows the measured concentrations of aliphatic aldehydes during binder blending and asphalt mixing for all samples. Aldehydes expected due to thermal decomposition of polymers include formaldehyde, acetaldehyde, and acrolein for which the allowable exposure limits set by Safe Work Australia (2022) are 1.2, 36, and 0.23 mg/m^3, respectively. Only formaldehyde was detected during the processing of all samples and so is the only one presented in Figure 3.8.

Figure 3.8: Total aldehydes detected (formaldehyde) during binder blending and asphalt mixing on the operator's person and static samplers; LOR for aldehydes is 0.25 µg per sampling tube and TWA for formaldehyde is 1.2 mg/m^3



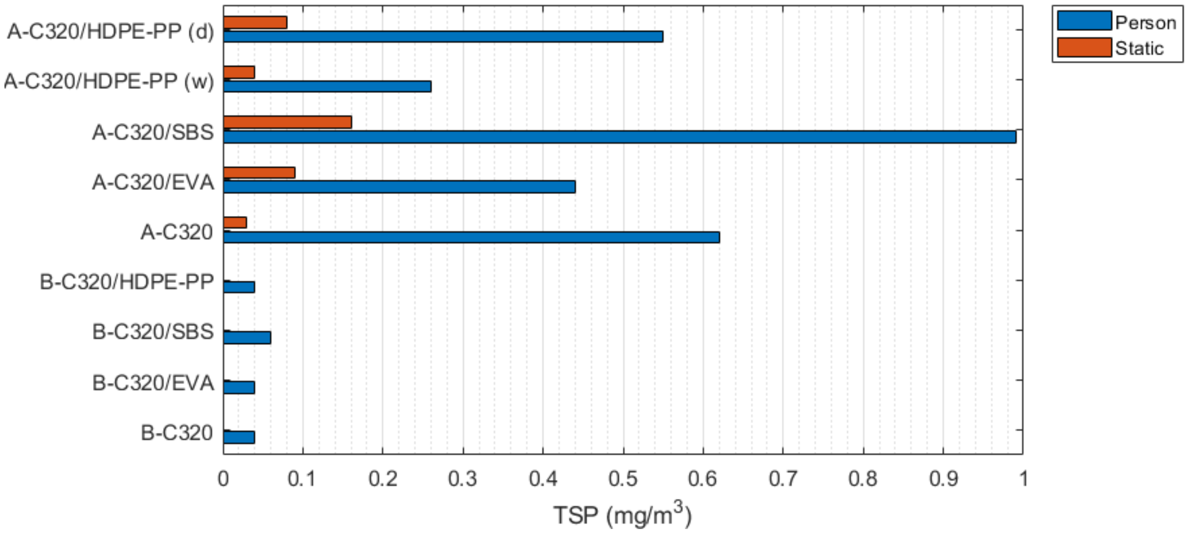
From Figure 3.8, the greatest concentration of formaldehyde was detected by the in-person sampler during asphalt mixing of sample A-C320/SBS at 0.009 mg/m^3 followed closely by the measurements collected during the mixing of the asphalt containing HDPE/PP via the dry method (A-C320/HDPE-PP (d)).

The incorporation of recycled HDPE/PP was only found to emit formaldehydes beyond those of the baseline samples (A-C320, A-C320/EVA, and A-C320/SBS) as measured by the static samplers during the asphalt mixing using the wet binder. During binder blending, the HDPE/PP containing binder (B-C320/HDPE-PP), was below the commonly used B-C320/EVA binder.

Total suspended particles and bitumen fumes

TSP is often primarily comprised of aerosols consisting of solids and condensed liquids suspended in air. Those inhalable are specified to particle size distribution with the 50th percentile below 100 µm. Due to the wide range of TSP, specific standards have not been set by Safe Work Australia, however, it is recommended that exposure to dusts that are low in toxicity and free from toxic impurities is limited to less than 10 mg/m^3. The Australian Institute of Occupational Hygienists (AIOH) though, proposed that these levels be kept below 5 mg/m^3. Those detected during binder blending and asphalt mixing of all samples are shown in Figure 3.9. BF were not detected above the quantification limit for any of the samples.

Figure 3.9: TSP detected during binder blending and asphalt mixing on the operator's person and static samplers; LOR for TSP is 0.01 mg per filter and AIOH proposes an upper limit of exposure of 5 mg/m³



TSP levels detected during binder blending had concentrations well below 0.1 mg/m³. According to Figure 3.9, the greatest amount of TSP detected within the operator's breathing zone during binder blending was for the sample containing SBS (B-C320/SBS). Similarly, the sample containing SBS (A-C320/SBS) was also the one that released the greatest amount of TSP during asphalt mixing as measured by both the in-person and static detectors.

The incorporation of HDPE/PP was not found to result in the increase of emitted TSP in any of the cases when compared to the baseline samples.

3.1.5 Discussion and Recommendations

From the results in Section 3.1.4 and the expert report in Appendix B, it may be concluded that the measured concentration levels of VOCs, PAHs, TSP, BF, and aldehydes in both locations for all samples are well below those specified by Safe Work Australia exposure limits. This suggests that no harm to human health is likely to be caused during binder blending and asphalt mixing using any of the investigated materials. It needs to be noted, however, that these measurements are always dependent on the bitumen grade and source, processing temperatures, as well as all additives in use. It is safe to expect though, that the comparative observations would not be affected by these factors.

Importantly, the incorporation of recycled plastics was only found to increase the detected concentrations of fumes and emissions in some cases. These were limited to:

- Aromatic hydrocarbons concentration (toluene) for sample A-C320/HDPE-PP (d).
- Naphthalene for samples B-C320/HDPE-PP and A-C320/HDPE-PP (d)
  - the static sampler for A-C320/HDPE-PP (d) was the only one that detected naphthalene during asphalt mixing.
- Formaldehyde concentration for sample A-C320/HDPE-PP (w) detected by the static sampler
  - A-C320/HDPE-PP (w) was the only mix for which the emission of formaldehyde was detected by the static sampler.

Therefore, it can be recommended that the PPE currently used during binder blending and asphalt mixing should suffice when the incorporation of the investigated comingled plastics is considered. This includes a face shield, safety boots, safety glasses, heat resistant gloves, and lab coat. It is also advisable that binder blending takes place in a fume cabinet.

Porot et al. (2020) observed that VOCs and PAHs emitted by unmodified bitumen samples were greater than these of modified binders. Although they recognised the need for further investigations to be undertaken, they proposed that this could be the result of an azeotrope effect. It is possible that the incorporation of additives has altered the boiling temperature of the bitumen resulting in a variance in the fumes and emissions released.

Forrest et al. (1995) studied the release of fumes and emissions during the extrusion and injection moulding of several common polymers, including these commonly found to accumulate in Australian landfills, like acrylonitrile butadiene styrene (ABS), HDPE, LDPE, linear low LDPE (LLDPE), polyamide 6 (PA6), and polyvinylchloride (PVC). They found concentrations of individual chemical species well below the limits of exposure at the time of the assessment. Although these observations are encouraging, when considering their incorporation in bitumen and asphalt, care needs to be taken to understand whether chemical reactions that could cause the increase of the released fumes and emissions are taking place. Also, it needs to be noted that, irrespective of whether such chemical reactions are indeed taking place, recycled plastics are different than their virgin counterparts due to aging caused by prolonged exposure to the environment and more extensive thermal cycling due to re-processing. These differences may be found at a molecular level, where chain scission or post-polymerisation are probable, and at a physical level, where changes in crystallisation and embrittlement may be observed (Do et al. 1987). Therefore, release of fumes and emissions from recycled plastics needs to be studied separately. With this in mind, Austroads (2022a) investigated the release of fumes and emissions during binder blending and asphalt mixing. It demonstrated a worst-case scenario where measurements were taken within an enclosed chamber. Even though the method is efficient in conducting a comparative analysis among different materials, it is not representative of the exposure of the operator (Austroads 2022a).

Although many of the investigated compounds were not detected during these measurements, investigating the presence of benzo(a)pyrene should always be considered due to its carcinogenic nature. Austroads (2022a) reported quantities of benzo(a)pyrene during its investigation that took place within an enclosed chamber. This means that such PAH is generated during binder blending and asphalt mixing, but the released amounts are not detectable in locations that would affect the operator undertaking the task. Additionally, even though the binder blending temperature was relatively high, at 180 °C, care needs to be taken when higher temperatures are considered, as Austroads (2022a) demonstrated a correlation between blend temperature and the release of VOCs, TSP, and PAHs. The decrease of the release of such fumes and emissions, when observed, may be related to the decreased amount on bitumen present in the process. Austroads (2022a) showed a correlation between emissions concentration and sample size.

3.2 Part B: Assessment of Selected Plastics Through Developed Monitoring Protocol

Following the findings from Section 3.1, it was decided that although understanding the fumes and emissions released to the laboratory environment affecting the operator’s breathing zone and other laboratory operators working in close proximity is necessary, absolute measurements of the binder fumes and emissions would also be beneficial. Therefore, the assessment of the selected materials was completed in both levels.

3.2.1 Materials

The unmodified bitumen used for this investigation was C170, a common base binder for polymer modified mixes. The selected polymers for the baseline PMB mixture, as for the preliminary investigations, were SBS and EVA. Measurements during the blending of recycled comingled HDPE/ PP and pelletised LDPE with the C170 bitumen were conducted to investigate whether the exposure effects are amplified by their presence. The bitumen used was tested to comply with both AS 2008 and Specification 511 (Main Roads Western Australia 2021) to meet both Queensland and Western Australia requirements (certificate included in Appendix E). The different blends and mixtures are henceforth referred to by their sample ID, as listed in Table 3.2. All binder blending was undertaken at 4,000 rpm for 1 hour at 180 ± 10 °C. The asphalt was mixed at 160 ± 10 °C.

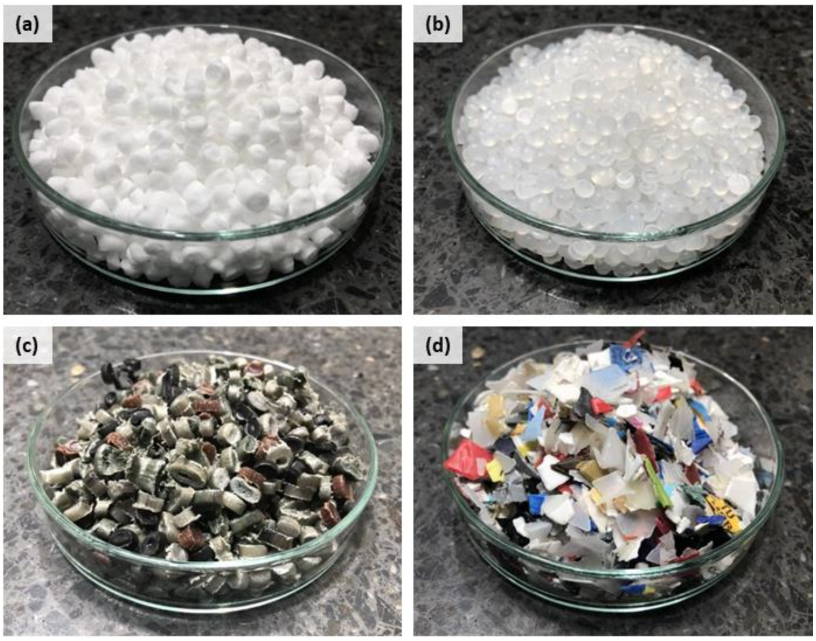
Table 3.2: Binder and asphalt naming convention and process parameters during the binder blending and asphalt mixing process

Sample ID	Additive	Content of additive (%)
Binder blending		
B-C170	N/A	0
B-C170/EVA	EVA	6
B-C170/SBS	SBS	6.5 (+7 wt.% combining oil)
B-C170/HDPE-PP	HDPE/PP	10
B-C170/LDPE	LDPE	10
Asphalt mixing		
A-C170	N/A	0
A-C170/EVA	EVA	0.3
A-C170/SBS	SBS	0.3
A-C170/HDPE-PP (w)	HDPE/PP	0.5
A-C170/HDPE-PP (d)	HDPE/PP	1.5
A-C170/LDPE (w)	LDPE	0.5
A-C170/LDPE (d)	LDPE	1.5

All binder blending and asphalt mixing were conducted as described in Section 3.1.2. B-C170/SBS was tested and met the requirements for an A10E and B-C170/EVA was ensured to meet the requirements for an A35P according to ATS 3110 (Austroads 2020).

The materials used for this component of the research are the binders and the slabs as listed in Table 3.2. The additives used to modify the C170 are shown in Figure 3.10.

Figure 3.10: Bitumen additives: (a) SBS, (b) EVA, (c) LDPE, and (d) HDPE-PP



Asphalt slabs of 305 x 305 x 50 mm^3 were prepared using C170 bitumen and different additives, as listed, using both the wet and dry method. Three types of PMBs were used, containing SBS and EVA, a comingled HDPE/PP, a pelletised LDPE, and unmodified C170 bitumen. The bitumen was prepared using a Silverson high shear mixer. Both the bitumen preparation and asphalt mixing process are described in Section 3.1.1.

3.2.2 Sampling Protocol

Laboratory fumes and emissions measurement

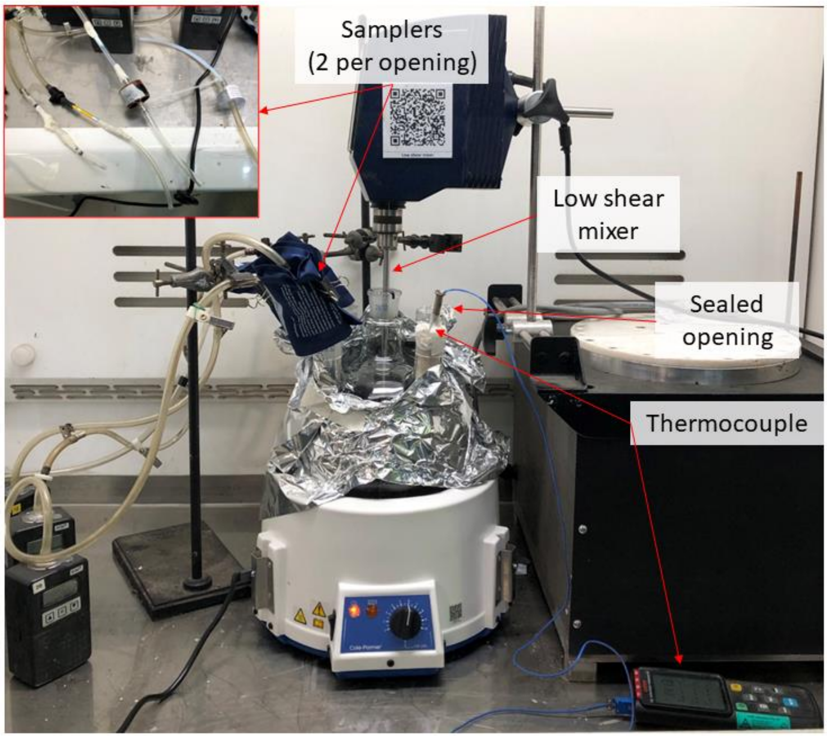
Although the results from testing conducted in Part A in Section 3.1.4 indicated that the fumes and emissions were well below the Safe Work Australia limits, it was still necessary to quantify them for the materials and concentrations selected for Part B of Task 6A. The mounting of the sensors for the in-person measurements was as depicted in Figure 3.4. The static sensors were once again moved following the operator's movements during the asphalt mixing. However, it was observed that the fume hoods were absorbing most of the fumes and emissions during blending and the static sensors were relocated during that process as shown in Figure 3.11.

Figure 3.11: Placement of static samplers during binder blending

Enclosed test chamber fumes and emissions measurement

In addition to the laboratory fumes and emissions measured, an effort to measure the fumes and emissions of the binders within an enclosed test chamber at elevated temperatures was also made. To achieve this, 500 g of the binders listed in Table 3.2 were poured in 5,000 ml 5-neck flasks and heated to 180 ± 10 °C, according to continuous monitoring by a thermocouple placed in the binder through one of the flask's necks, in a heating mantle. Samplers for VOCs, PAHs, and TSPs/ BFs were placed in each of the remaining openings as illustrated in Figure 3.12. One specimen of each sample was monitored in this research.

Figure 3.12: Location of samplers for enclosed test chamber fumes and emissions measurements



The sampling devices and analysis methods for these measurements were as described in Section 3.1.3.

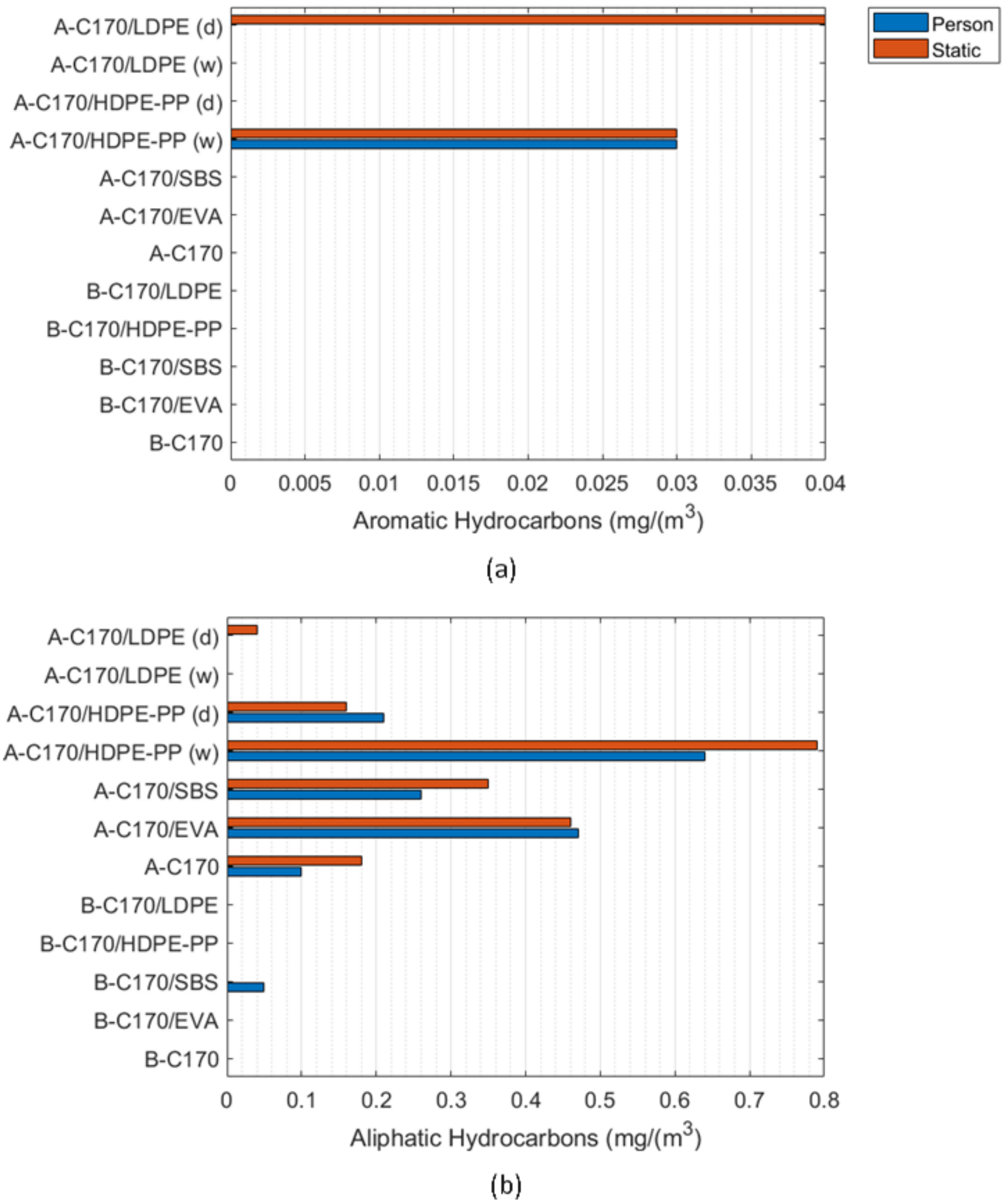
3.2.3 Results

The fumes and emissions results following the in-person and static laboratory measurements are presented in Figure 3.13 to Figure 3.16. These are calculated based on TWA, which refers to exposure in a 5-day work week assuming 8 hours of work per day. Further details are provided in Appendix B.

Volatile organic compounds (in-person and static)

Figure 3.13 shows the measured aromatic and aliphatic hydrocarbons for all binder blends and asphalt mixes of Table 3.2.

Figure 3.13: VOCs detected during binder blending and asphalt mixing on the operator's person and static samplers: (a) aromatic hydrocarbons and (b) aliphatic hydrocarbons; LOR for VOCs is 5 µg per sampling tube and TWA for total VOCs (aliphatic and aromatic hydrocarbons) is 790 mg/m^3



(a)

(b)

From Figure 3.13 (a), aromatic hydrocarbons were detected only for samples containing recycled plastics, namely A-C170/HDPE-PP (w) and A-C170/LDPE (d), and only during the asphalt mixing process.

From the measurements of the aliphatic hydrocarbons in Figure 3.13 (b), those with the greatest concentration were for sample A-C170/HDPE-PP (w) for both the in-person and static. For sample A-C170/HDPE-PP (w) a wide variety of VOCs, not common among the other samples, such as n-octane, n-nonane, n-decane, and 1,2,4-trimethyl benzene were detected. N-pentane and 2-methyl butane were not only present in sample A-C170/HDPE-PP (w), but they were also the only VOCs emitted by samples A-C170, A-C170/EVA, A-C170/SBS, A-C170/HDPE-PP (d) where they were detected by both the in-person and static samplers. N-pentane and 2-methyl butane were also detected by the static sampler for sample A-C170/LDPE (d). It is noted that 2-methyl butane does not have a set exposure limit by the Safe Work Australia standards.

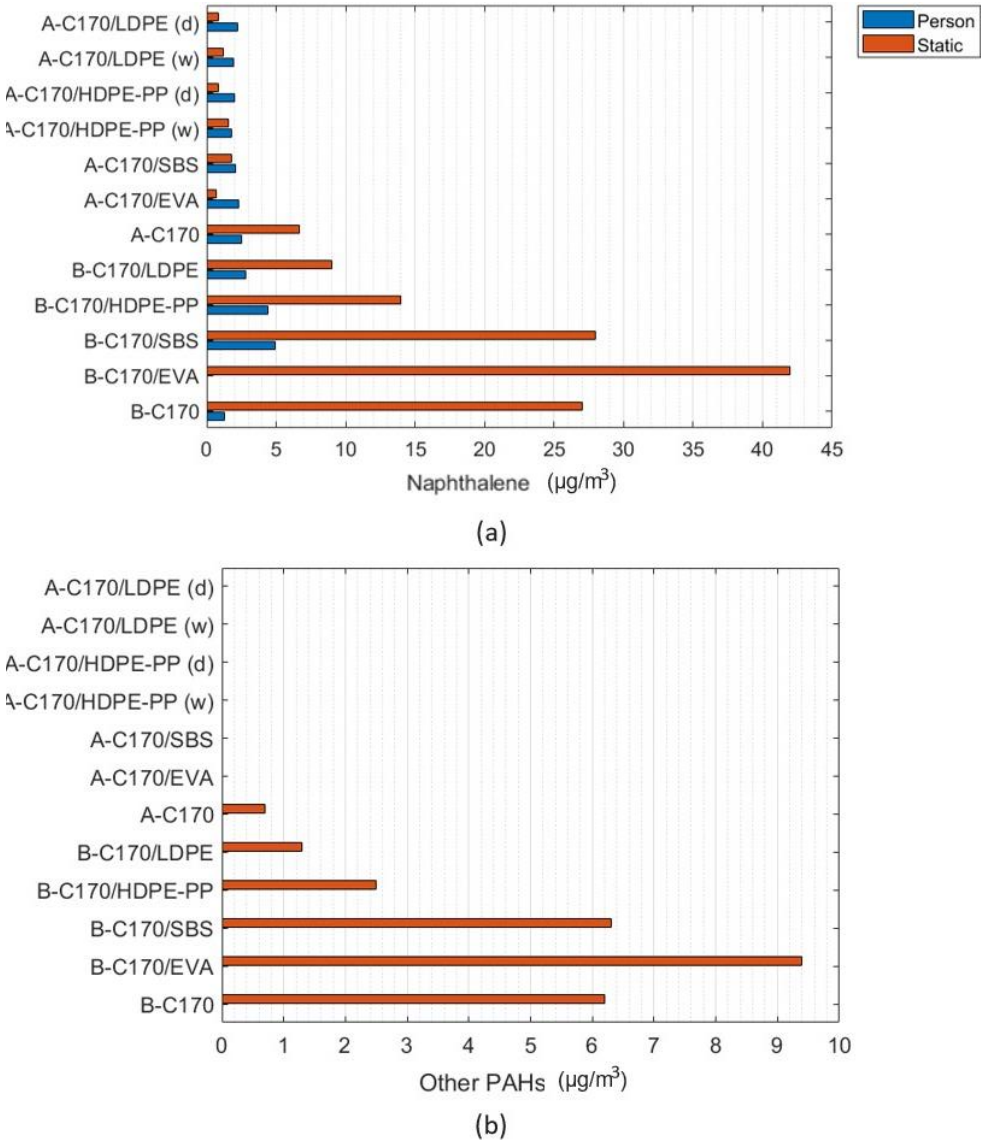
The only aliphatic hydrocarbon detected during binder blending was n-undecane by the in-person sampler for sample B-C170/SBS, while none was detected for either of the recycled plastics-containing blends. N-undecane does not have a workplace exposure standard set. Unlike these results, Porot et al. (2020) noted a greater concentration of VOCs being released by the base bitumen of their work (50/70 penetration grade) when compared to an SBS-modified binder. Differences in the sampling and analysis methods as well as the fact they only targeted alkanes, monocycloparaffins, and alkyl-benzenes, which were not detected in this research could be responsible for these findings.

From these measurements, it may be understood that the incorporation of recycled plastics may result in the emission of aromatic hydrocarbons otherwise not detected. All VOCs detected, however, were measured to be well below the Safe Work Australia standards, in the cases where such standards are set.

Polycyclic aromatic hydrocarbons (in-person and static)

Figure 3.14 shows the measured PAHs during the blending and mixing of all samples listed in Table 3.2.

Figure 3.14: **PAHs detected during binder blending and asphalt mixing on the operator's person and static samplers: (a) naphthalene and (b) other PAHs; LOR for PAHs is 0.1 µg per sampling tube or filter and TWA for naphthalene is 52 mg/m^3; no other PAH has a set TWA**



(a)

(b)

As shown in Figure 3.14 (a), naphthalene was detected in all samples and by both in-person and static samplers, with the only exception being for sample B-C170/EVA for which naphthalene was not detected by the in-person sampler. The greatest concentration of naphthalene during binder blending was detected during the blending of sample B-C170/EVA followed by sample B-C170/SBS and then by sample B-C170. Sample A-C170 was the one for which the greatest concentration of naphthalene was detected during the asphalt mixing process. Although naphthalene was detected during the mixing of all asphalt samples, all others were notably below that of A-C170. All measured naphthalene was below the Safe Work Australia (2022) limit of 52 mg/m^3.

Other than naphthalene, PAHs were detected for all samples during binder blending, while only that of A-C170 was found to emit other PAHs during the asphalt mixing process. All other PAHs were detected by the static samplers. The greatest concentration of other PAH was measured for sample B-C170/EVA followed by B-C170/SBS and B-C170. These findings are also the opposite of the findings by Porot et al. (2020) as discussed also for VOCs. This highlights the significance of base bitumen as well as the methods for sampling and analysis when results are to be compared and consequently the need for a broadly accepted testing and assessment framework. A summary of the other PAHs detected is presented in Table 3.3.

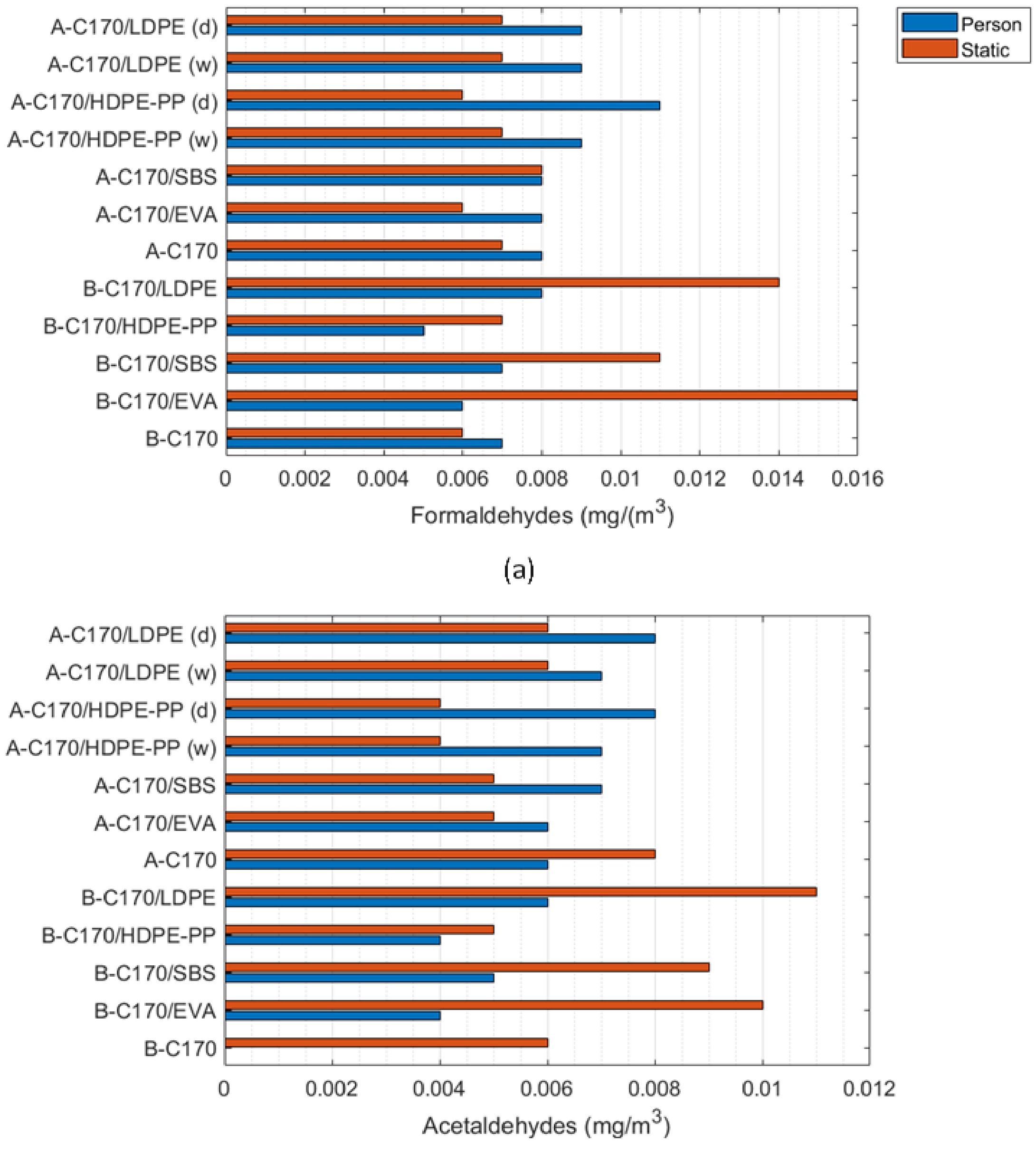
Table 3.3: Summary of other PAHs detected

Samples	PAH
B-C170	Biphenyl, acenaphthylene, acenaphthene, fluorene, phenathrene
B-C170/EVA	Biphenyl, acenaphthylene, acenaphthene, fluorene, phenathrene
B-C170/SBS	Biphenyl, fluorene, phenathrene
B-C170/HDPE-PP	Biphenyl, acenaphthene, fluorene
B-C170/LDPE	Biphenyl, acenaphthene, fluorene
A-C170	Biphenyl

Aldehydes (in-person and static)

Figure 3.15 shows the measured aldehydes during the blending and asphalt mixing of all samples listed in Table 3.2 by both the in-person and static samplers. Formaldehyde and acetaldehyde were detected, while other aliphatic aldehydes, such as acrolein, crotonaldehyde, and n-valeraldehyde, although common were not.

Figure 3.15: Aldehydes detected during binder blending and asphalt mixing on the operator's person and static samplers: (a) formaldehydes and (b) acetaldehydes; LOR for aldehydes is 0.25 µg per sampling tube and TWA for formaldehyde is 1.2 mg/m^3 and for acetaldehyde it is 36 mg/m^3



(a)

(b)

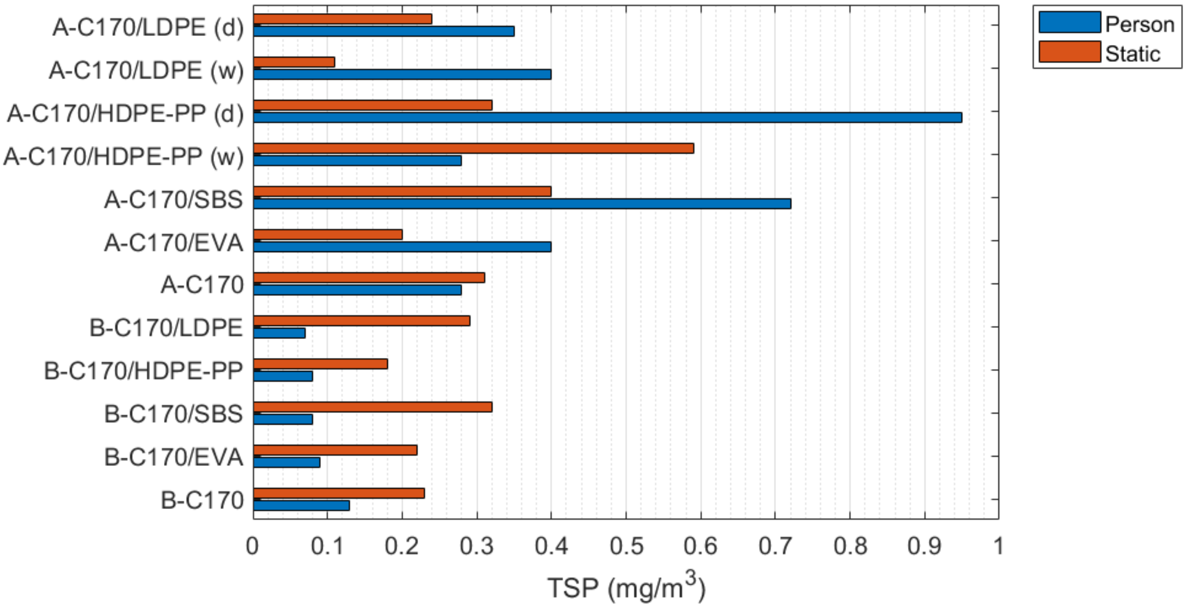
As shown in Figure 3.15 (a), formaldehyde was detected for all samples and by both the static and in-person samplers. During binder blending, the greatest concentration of formaldehyde was detected for sample B-C170/EVA by the static sampler followed by that of sample B-C170/LDPE. During asphalt mixing, the greatest concentration of formaldehyde was detected by the in-person sampler for sample A-C170/HDPE-PP (d). All other samples containing recycled plastics, namely A-C170/HDPE-PP (w), A-C170/LDPE (w), and A-C170/LDPE (d) followed, all exceeding the formaldehyde emitted by the baseline samples (A-C170, A-C170/EVA, and A-C170/SBS). According to Safe Work Australia (2022), the workplace exposure limit for formaldehyde is 1.2 mg/m^3. All samples were measured to emit formaldehyde well below that upper limit.

All samplers, except the in-person for A-C170, measured acetaldehydes, as shown in Figure 3.15 (b). During binder blending, the static sampler for B-C170/LDPE measured the greatest concentration of acetaldehyde followed by B-C170/EVA. B-C170/LDPE was also measured to emit the greatest concentration of acetaldehyde by the in-person sampler followed by B-C170/SBS. During asphalt mixing, the dry mixes (A-C170/HDPE-PP (d) and A-C170/LDPE (d)) were found to emit the greatest concentration of acetaldehydes of 0.008 mg/m^3. The static sampler for sample A-C170 detected an equal amount of acetaldehydes to have been emitted as those of the in-person samplers for the dry mixes, measuring the greatest concentration of 0.008 mg/m^3. According to Safe Work Australia (2022), the workplace exposure limit for acetaldehydes is 36 mg/m^3, which is notably above the quantities measured by any of the samplers during either binder blending of asphalt mixing.

Total suspended particles and bitumen fumes (in-person and static)

Figure 3.16 shows the measured TSP during the blending and asphalt mixing of all samples listed in Table 3.2 by both the in-person and static samplers. BF measurements were all below the detection limit and so are not shown graphically.

Figure 3.16: TSP detected during binder blending and asphalt mixing on the operator's person and static samplers; LOR for TSP is 0.01 mg per filter and AIOH proposes an upper limit of exposure of 5 mg/m^3



During binder blending, the static sampler for sample B-C170/SBS detected the greatest concentration of TSP followed by that of B-C170/LDPE. The sample containing HDPE/PP (B-C170/HDPE-PP), was found to emit lower concentrations of TSP when compared to all baseline samples as detected by both the in-person and static samplers.

During asphalt mixing the greatest concentration of TSP was detected by the in-person sampler during the dry process when HDPE/PP was added (sample (A-C170/HDPE-PP (d)). The asphalt mixing of HDPE/PP through the wet method (sample A-C170/HDPE-PP (w)) was found to emit the greatest concentration of TSP as measured by the static sampler.

Volatile organic compounds (enclosed test chamber measurements)

The total aliphatic and aromatic hydrocarbons measured in the flask are summarised in Figure 3.17. All binders were pre-blended as the low shear mixer does not have the capacity to effectively blend the recycled plastics with the bitumen and the addition of the plastics in the flask during the process would have been complex given the size of the openings in the necks.

Figure 3.17: VOCs detected during binder blending in the enclosed test chamber: (a) aromatic hydrocarbons and (b) aliphatic hydrocarbons; LOR for VOCs is 5 µg per sampling tube

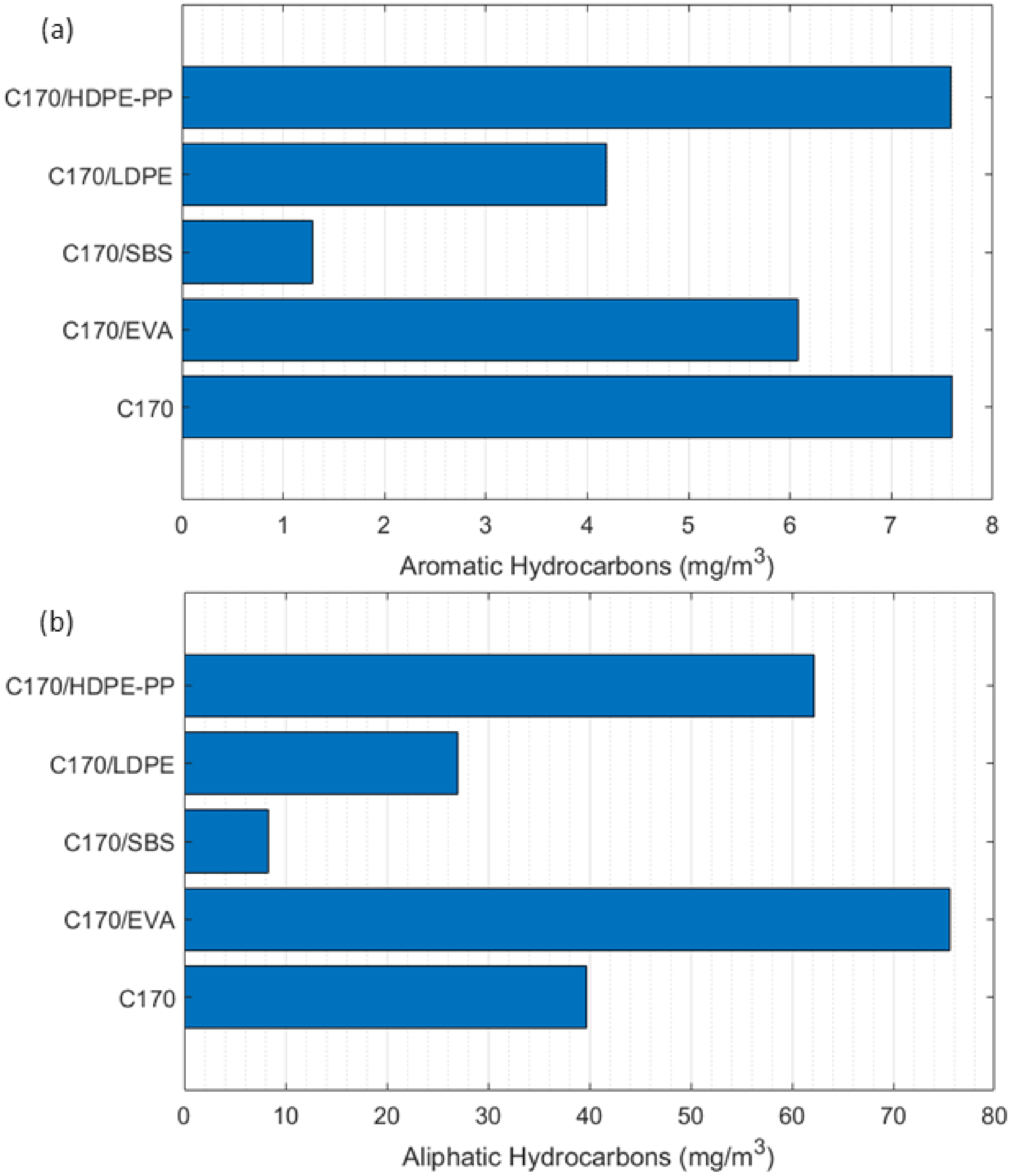


Figure 3.17 shows that the concentration of aliphatic and aromatic hydrocarbons emitted during the blending process for the binders containing recycled plastics was found to be below those of the commonly accepted binders (aromatic hydrocarbons for C170/HDPE-PP were 0.005 mg/m^3 below those of C170). Austroads (2022a) showed that C170 emitted the greatest concentration of total VOCs when compared to polymer modified binders. In this research, the total VOCs measured were in decreasing order for C170/EVA, C170/HDPE-PP, C170, C170/LDPE, and C170/SBS at 81.671, 69.740, 47.352, 31.141, and 9.541 mg/m^3, respectively.

The concentration of each aliphatic and aromatic hydrocarbon investigated and their concentrations detected for each sample are listed in Table 3.4. For C170, the analyte measured in the greatest concentration was n-tetradecane, for C170/EVA, C170/SBS, and C170/LDPE it was n-dodecane, and for C170/HDPE-PP it was n-undecane.

Table 3.4: VOC analytes detected during measurements of fumes and emissions undertaken in the enclosed test chamber

VOC	C170 (mg/m^3)	C170/EVA (mg/m^3)	C170/SBS (mg/m^3)	C170/LDPE (mg/m^3)	C170/HDPE-PP (mg/m^3)
Aliphatic hydrocarbons					
2-Methylbutane	0.266	0.064	0.066	0.097	0.129
n-pentane	0.500	0.095	0.099	0.227	0.226
2-methylpentane	0.266	0.064	0.066	0.097	0.129
3-methylpentane	0.133	0.032	–	0.065	0.065
Cyclopentane	0.100	–	–	0.032	0.032
Methylcyclopentane	0.167	0.032	–	0.065	0.065
2,3-dimethylpentane	0.167	0.032	–	0.065	0.065
n-hexane	0.599	0.127	0.099	0.260	0.258
3-methylhexane	0.266	0.064	0.033	0.097	0.129
Cyclohexane	0.233	–	–	–	–
Methylcyclohexane	0.266	0.159	0.066	0.130	0.226
2,2,4-trimethylpentane	–	–	–	–	–
n-heptane	0.799	0.223	0.133	0.324	0.387
n-octane	1.032	0.509	0.166	0.487	0.839
n-nonane	1.632	2.004	0.298	1.168	2.841
n-decane	2.498	8.015	0.530	3.146	8.944
n-undecane	3.830	20.990	0.961	5.871	16.176
n-dodecane	6.161	21.785	1.491	5.904	14.336
n-tridecane	9.957	12.849	1.955	4.574	9.008
n-tetradecane	10.889	8.555	2.319	4.347	8.298
Aromatic hydrocarbons					
Benzene	0.100	–	–	0.195	0.065
Ethylbenzene	0.366	0.159	0.066	0.162	0.291
Isopropylbenzene	0.067	0.064	–	0.032	0.097
1,2,3-trimethylbenzene	1.066	1.050	0.199	0.584	1.098
1,2,4-trimethylbenzene	2.431	2.353	0.431	1.395	2.615
1,3,5-trimethylbenzene	0.666	0.891	0.133	0.454	1.001
Styrene	–	–	–	–	–
Toluene	0.699	0.223	0.099	0.260	0.355
p-xylene and/ or m-xylene	1.432	0.891	0.232	0.746	1.421
o-xylene	0.766	0.445	0.133	0.357	0.646

Polycyclic aromatic hydrocarbons (enclosed test chamber measurements)

The total PAHs emitted within the enclosed chamber as measured in this research are presented in Figure 3.18. It was found that C170 emitted the greatest concentration of C170. These findings are in line with those discussed in Austroads (2022a).

Figure 3.18: PAHs detected during binder blending in the enclosed test chamber; LOR for PAHs is 0.1 µg per sampling tube or filter

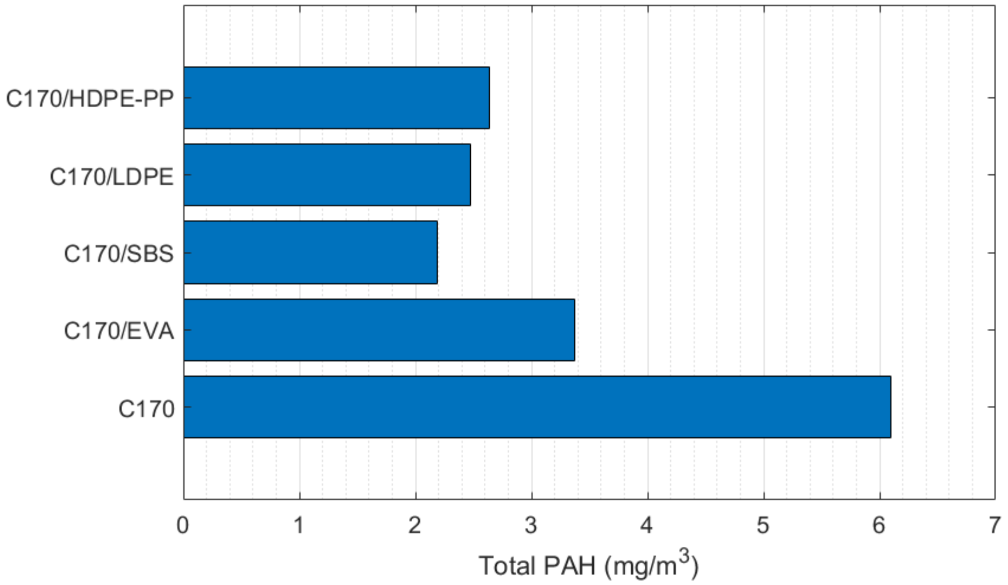


Table 3.5 lists the analytes investigated and the detected concentrations in all samples. Naphthalene was the analyte detected at the greatest concentration for all samples.

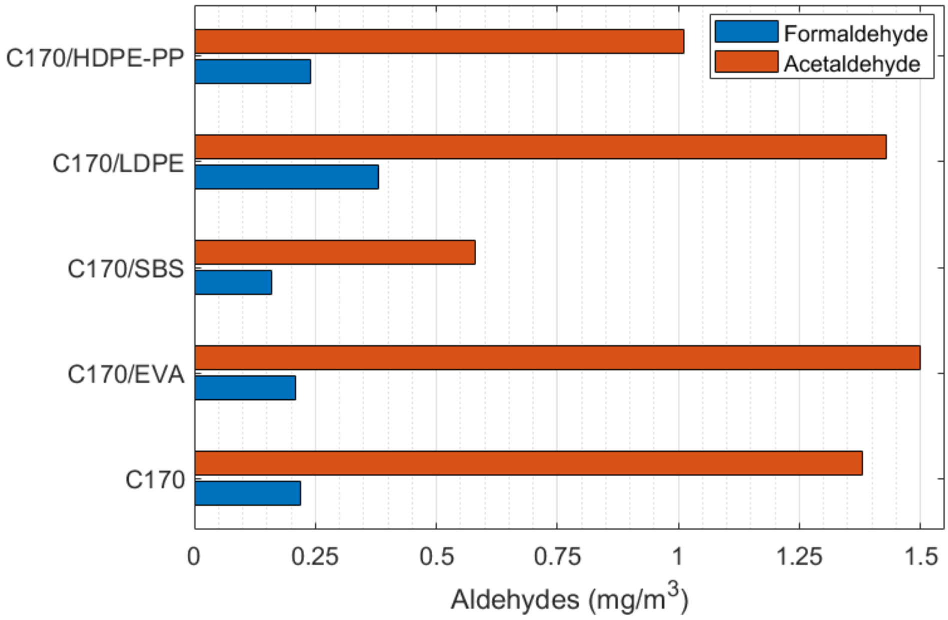
Table 3.5: PAH analytes detected during measurements of fumes and emissions undertaken in the enclosed test chamber

PAH	C170 (mg/m^3)	C170/EVA (mg/m^3)	C170/SBS (mg/m^3)	C170/LDPE (mg/m^3)	C170/HDPE-PP (mg/m^3)
Naphthalene	2.529	1.409	0.884	1.295	1.087
Biphenyl	1.438	0.767	0.417	0.466	0.506
Acenaphthylene	0.172	0.098	0.060	0.058	0.083
Acenaphthene	0.894	0.436	0.290	0.261	0.348
Fluorene	0.812	0.470	0.381	0.285	0.453
Phenanthrene	0.234	0.162	0.139	0.094	0.140
Anthracene	–	0.018	0.010	0.010	0.013
Fluorathene	–	0.001	–	–	–
Pyrene	0.013	0.010	0.005	0.004	0.007
Benz(a)anthracene	0.002	0.001	0.001	–	0.001
Chrysene	0.004	0.002	–	0.002	0.002
Benzo(b)fluoranthrene	–	–	–	–	–
Benzo(k)fluoranthrene	–	–	–	–	–
Benzo(a)pyrene	–	–	–	–	–
Indeno(1,2,3-cd)pyrene	–	–	–	–	–
Bibenz(a,h)anthracene	–	–	–	–	–
Benzo(ghi)perylene	–	–	–	–	–

Aldehydes (enclosed test chamber measurements)

As observed by the static and in-person samplers, formaldehyde and acetaldehyde were the 2 aldehydes detected by the measurements in the enclosed test chamber. These are presented in Figure 3.19. In the measurements undertaken, the greatest concentration of formaldehydes was measured for the binders containing LDPE (C170/LDPE) and the greatest concentration of acetaldehyde was found in the binders with EVA (C170/EVA).

Figure 3.19: Aldehydes detected during binder blending in the enclosed test chamber

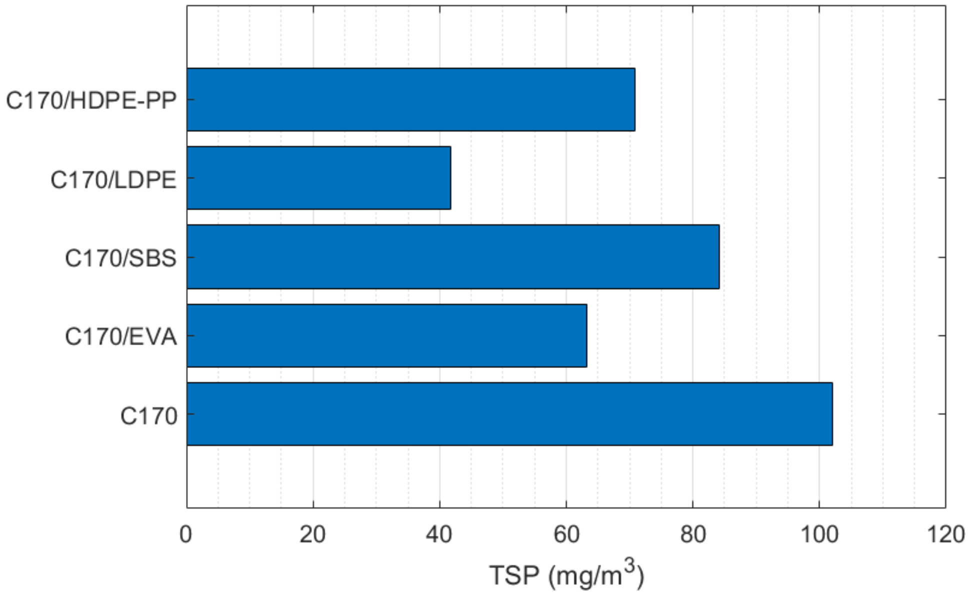


In this research, the total aldehydes detected were in decreasing order for C170/LDPE, C170/EVA, C170, C170/HDPE-PP, and C170/SBS at 1.81, 1.71, 1.60, 1.25, and 0.74 mg/m^3, respectively.

Total suspended solids and bitumen fumes (enclosed test chamber measurements)

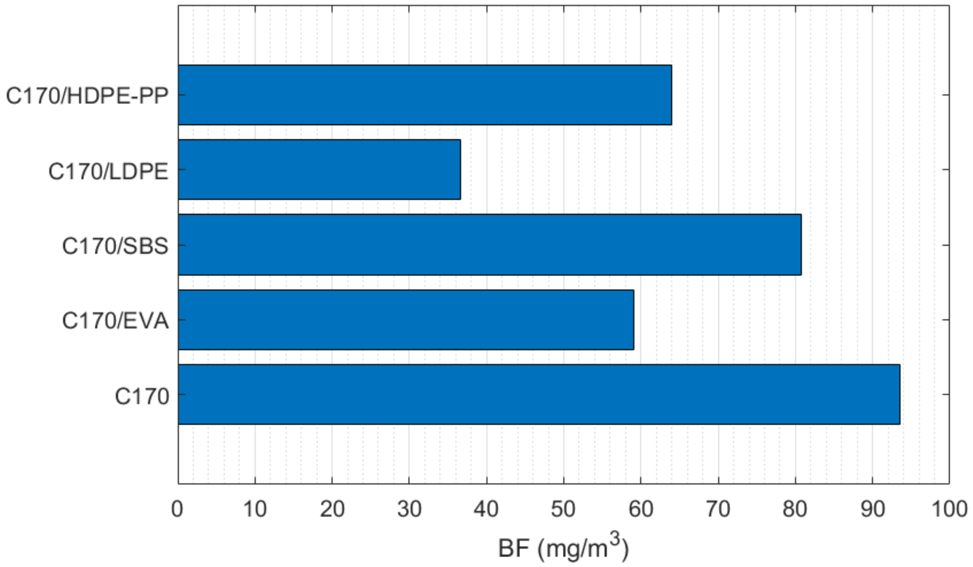
The measured TSPs are shown in Figure 3.20. It was found that the greatest concentration of TSP was released during the blending of unmodified C170.

Figure 3.20: TSP detected during binder blending in the enclosed test chamber. LOR for TSP is 0.01 mg per filter



Unlike the findings from the in-person and static samplers, BF were detected in the enclosed chamber test. The results are shown in Figure 3.21. C170 was also found to emit the greatest concentration of BF followed by C170/SBS, C170/HDPE-PP, C170/EVA, and C170/LDPE in decreasing order. The trend of the released BF was found to be the same as that of TSP.

Figure 3.21: BF detected during binder blending in the enclosed test chamber



3.2.4 Discussion

Overall, fumes and emissions measured by static and in-person samplers were found to be well below the Safe Work Australia exposure limits and comparable with those measured for the baseline materials. Therefore, the currently used PPE was deemed sufficient.

The incorporation of recycled plastics was found to result in the increased emission of VOCs, PAHs, aldehydes, and TSP in the following cases:

- aromatic hydrocarbons as measured by the static sampler by A-C170/HDPE-PP (w) and A-C170/LDPE (d)
- aromatic hydrocarbons as measured by the in-person sampler by A-C170/HDPE-PP (w)
- aliphatic hydrocarbons as measured by both the static and in-person samplers by A-C170/HDPE-PP (w)
- formaldehyde as measured by the in-person sampler by B-C170/LDPE and A-C170/HDPE-PP (d)
- acetaldehydes as measured by the static sampler by B-C170/LDPE
- acetaldehydes as measured by the in-person samplers by B-C170/LDPE, A-C170/HDPE-PP (d), and A-C170/LDPE (d)
- TSP as measured by the static sampler by A-C170/HDPE-PP (w)
- TSP as measured by the in-person sampler by A-C170/HDPE-PP (d).

As a result, no changes to current laboratory practices were considered to be necessary. For the assessment of worker exposure to fumes and emissions, the placement of the in-person samplers was appropriate and the analysis methods used for the analysis of the results nationally recognised. The location of the static samplers during binder blending was found to make a difference, as greater concentrations were detected when the samplers were placed inside the fume cupboard compared to the placement depicted in Figure 3.4. It needs to be noted here that changing the base bitumen from C320 to C170 may also influence these findings. This effect may be quantified through a comparison of the in-person samplers for Part A and Part B as their location was not changed and, hence, any variations are due to the difference in materials used (type, grade, and concentration). In addition, should the impact on other operators within the laboratory be of interest, placing the static samplers outside the fume cupboard is considered more appropriate.

From the results obtained by measurements undertaken in an enclosed test chamber, it was observed that commonly accepted materials emitted greater concentrations of the investigated fumes, except for formaldehyde which was found at greatest concentrations in sample C170/LDPE followed by sample C170/HDPE-PP. It needs to be noted, however, that these findings are for the specific binders investigated and for measurements undertaken throughout the course of 2 consecutive days.

It is recommended that this assessment is undertaken for more than one specimen in each sample. Austroads (2022a) research previously demonstrated the dependency of measurements undertaken in an enclosed environment on the type and concentration of polymer additives as well as the temperature of the binder during measurement. Therefore, even though the findings of this project consistently indicated that the addition of recycled plastics did not result in the emission of significantly greater concentration of fumes when compared to those commonly accepted by the industry materials (C170, C170/EVA, and C170/SBS), a comparative assessment should be undertaken for any new binders of interest.

4 Task 6B: Environmental Impacts – Detailed Test Methodology for Measuring the Content of Microplastics and Leaching Potential

4.1 Part A: Preliminary Investigation

In this section, the preparation of the materials used to measure their content in microplastics as well as the ARRB-developed test methodology to generate contaminated specimens and measure their content in microplastics and the leachability of the binders are described.

4.1.1 Materials

The materials used are the binders and the slabs as listed in Table 3.1. Asphalt slabs of 305 x 305 x 50 mm^3 were prepared using C320 bitumen and different additives as listed. These slabs were prepared using the wet and dry method and are henceforth referred to by their allocated naming conventions. Three types of PMBs were used, containing SBS and EVA, a waste comingled plastic, and unmodified C320 bitumen. The bitumen was prepared using a Silverson high shear mixer. Both the bitumen preparation and asphalt mixing process are described in Section 3.1.1. Following manufacture, the asphalt slabs were conditioned for 120 ± 0.5 hours in an air forced oven at 85 ± 3 °C, as per AASHTO R30-02 (AASHTO 2015) prior to abrasion as described in Appendix F.3.

4.1.2 Proposed Test Protocol

In this section, the method used to generate particulate matter simulating that in roads is described. In addition, 2 methods for the quantification of the released microplastics are assessed. A method to assess the potential of the binder to leach to the environment is also evaluated.

Leachability

To investigate the leachability of the binders as listed in Table 3.1, the methodology proposed by White (2019) was followed. To prepare the specimens for analysis involved the following steps:

- An amount of 2.5 g of each binder as well as the as-received HDPE-PP were placed in glass beakers and submerged in 50 mL of deionised water.
- The containers were then covered with aluminium foil and placed in an air forced heating oven at 40 °C for 18 hours.
- After exposure, the potentially contaminated water was filtered through a 4 µm mesh filter and collected in a glass container.
- The water was then cold evaporated under N_2 atmosphere, and the residue was submerged in 5 mL of ethanol (Merck, spectroscopy grade) for GC/MS.

The ethanol solutions of the 4 binder leachates, the one from the HDPE-PP, and an ethanol blank were analysed using a Perkin Elmer Clarus 580 gas chromatography coupled with a Perkin Elmer Clarus SQ 8S mass spectrometer. The instrument was set for 1 µL injection volume using He as the carrier gas at 1 mL/min. The oven temperature was isothermally held at 40 °C for 2 minutes then heated up to 85 °C at 15 °C/min and then to 300 °C at a rate of 10 °C/min where it was isothermally held for 15 min. The mass spectrometer scan range was over a mass-to-charge ratio (m/z) from 35 to 550.

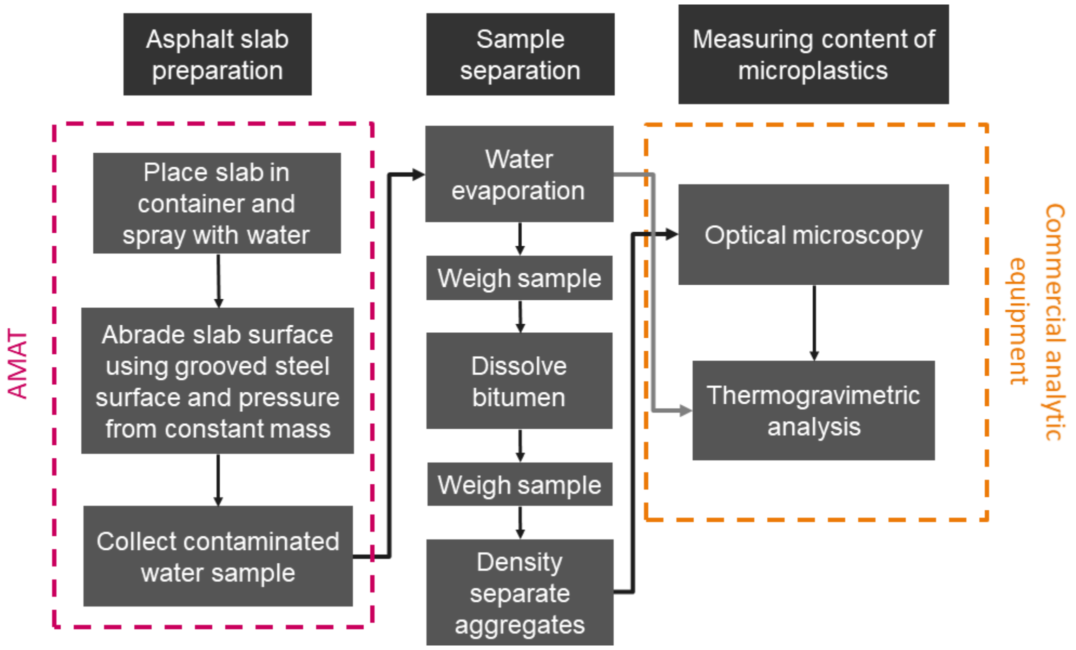
The gas chromatograph peaks reflect the number of identified compounds which are then compared against the National Institute of Standards and Technology MS library for identification.

Microplastics

Microplastics are specified as particles with sizes ranging from 1 to 5,000 µm (Järlskog et al. 2020) and therefore all generated samples were sieved through a 5 mm sieve prior to further investigation. A specific device to simulate the release of contaminants was designed by ARRB. This device was named the Accelerated Microplastic Abrasion Test (AMAT) and is described in detail in Appendix F. The commercial analytical equipment used is discussed in this section.

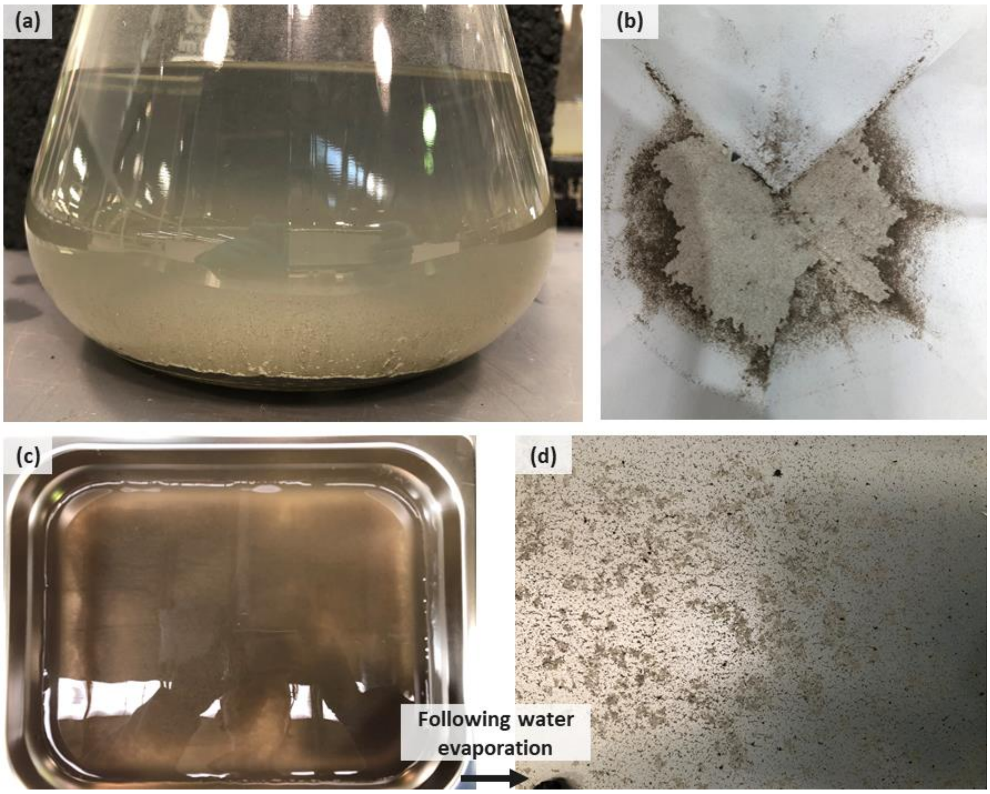
A test protocol for the quantification of microplastics was developed from the proposed methods in Appendix F.3. This is shown in the flowchart of Figure 4.1.

Figure 4.1: Proposed testing protocol



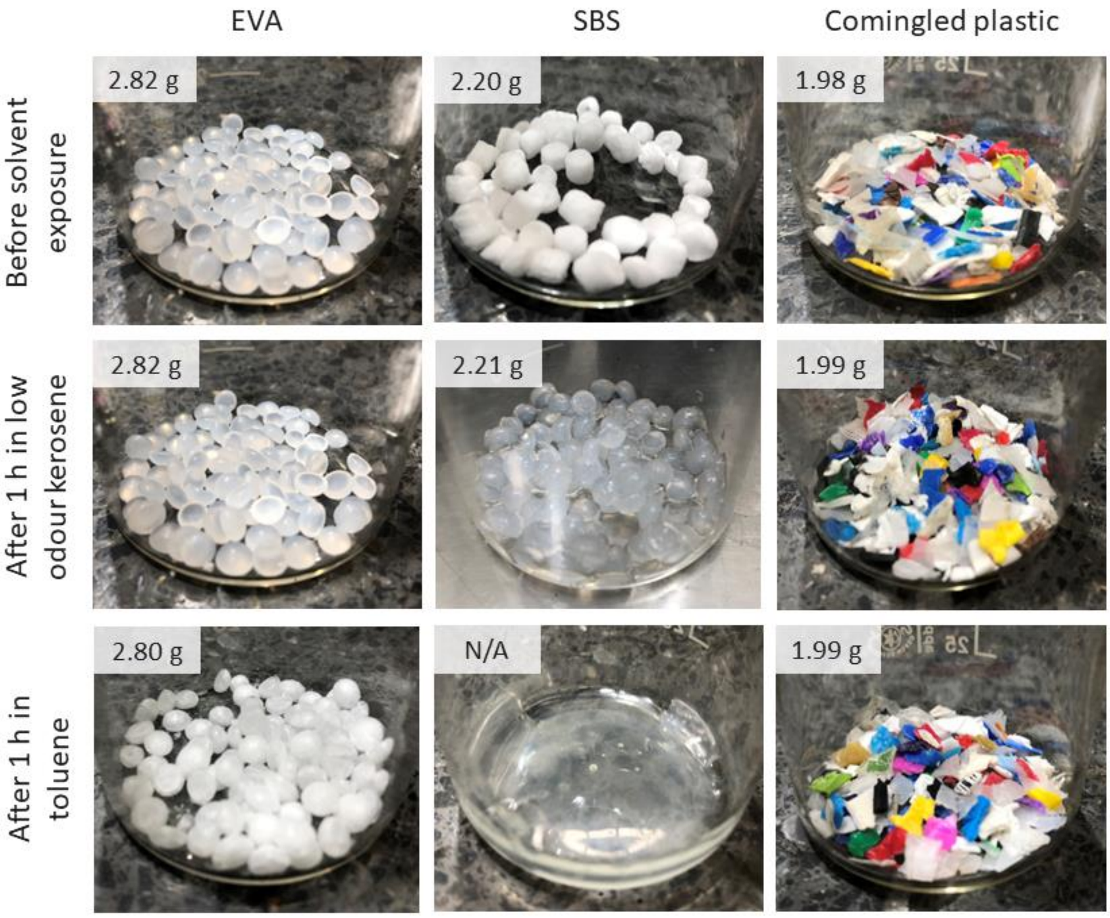
The samples were generated using the AMAT and collected in water (Figure 4.2 (a)). All slabs were abraded for 120 min. Filtering for the collection of the solid particles was examined using 4 µm mesh filters, but the smaller dust particles were found to be trapped in the filter and impossible to retrieve, as shown in Figure 4.2 (b). Therefore, the water was evaporated in a Thermoline scientific dehydrating oven at 75 °C. The samples were placed in trays (Figure 4.2 (c)) covered with perforated aluminium foil and left in the oven until all water was evaporated (Figure 4.2 (d)). All solid matter was then collected from the trays and placed in glass sample vials.

Figure 4.2: AMAT-collected samples: (a) water from tray, (b) particles unretrievable from 4 µm filter, (c) water sample in tray, and (d) dried sample in tray



To identify a solvent that would dissolve the bitumen, but not affect the polymer additive during the bitumen dissolution step, 2 solvents known to be effective for bitumen and are typically available in binder and asphalt laboratories were tested on the polymers investigated. The polymers were exposed to low odour kerosene and toluene for 1 hour and any variances in weight were measured using an FZ-5000i balance from A&D Company with 0.01 g accuracy and their appearance was visually qualified. These are shown in Figure 4.3. The use of dichloromethane as a solvent for both bitumen dissolution and density separation was also considered, however, its use in the laboratory was not permitted.

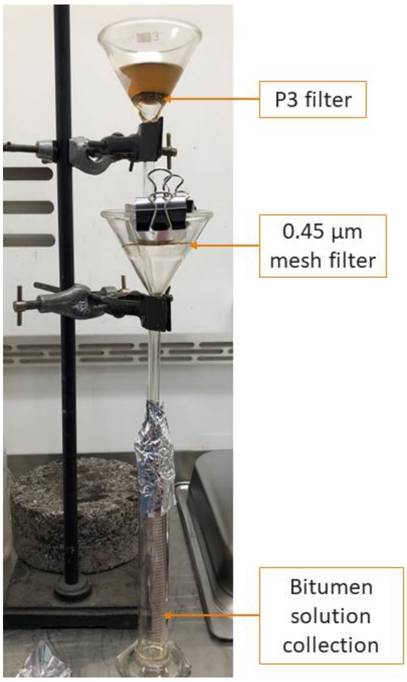
Figure 4.3: Effect of low odour kerosene and toluene exposure on investigated polymers



From Figure 4.3, it may be understood that the comingled plastic (HDPE/PP) remained unaffected by either of the solvents, the EVA showed a 0.02 g decrease in weight and a change in appearance, where it became opaque, after exposure to toluene while remaining unaffected by the low odour kerosene. The SBS was affected by both solvents used. During email correspondence with Dr Robert Urquhart (ARRB) on 8 April 2022, it was concluded that dissolving bitumen without affecting the SBS is not possible due to the similarities in the solubility parameters among bitumen, polystyrene, and polybutadiene. Hence, it may be concluded that the proposed methodology is limited when quantification of SBS in bitumen is considered. The SBS-containing samples were still analysed through TGA.

For the bitumen dissolution step, 0.7500 g of each sample was submerged in 30 mL of low odour kerosene and stirred using magnetic stirring (intensity 2) for 15 min. Next, a glass pipette was used to collect the bitumen solution which was then put through a filtered Pyrex with P3 designation (16–40 µm) followed by a 0.45 µm mesh filter (47 mm in diameter). The set-up for this process is depicted in Figure 4.4.

Figure 4.4: Bitumen dissolution set-up



This process was repeated until the solution was visually clear of bitumen. The remaining solvent was allowed to evaporate and then further dried in the oven at 50 °C for 1 hour, weighed and then put in 30 mL of glycerine to separate any plastics from the aggregates through density separation. The floating plastics were then collected using a pipette and placed in glass slides for qualification in the optical microscope. The glycerine was then filtered through a 4 µm mesh filter and the aggregates were then weighed.

As suggested in Figure 4.1, gravimetric data were collected after each step of the process using an OHAUS Explorer balance with 0.0001 g accuracy. To acquire the gravimetric data a series of assumptions were made:

- All particulates trapped in all filters were assumed to be aggregates.
- After density separation, the suspended plastics were efficiently collected from the top layer.
- No other mass loss or uptake was taken into consideration.

Optical microscopy was conducted using an Olympus BX-53 optical microscope with a SC30 camera under visible and ultraviolet (UV) light and a polarised lens to visually inspect the specimens.

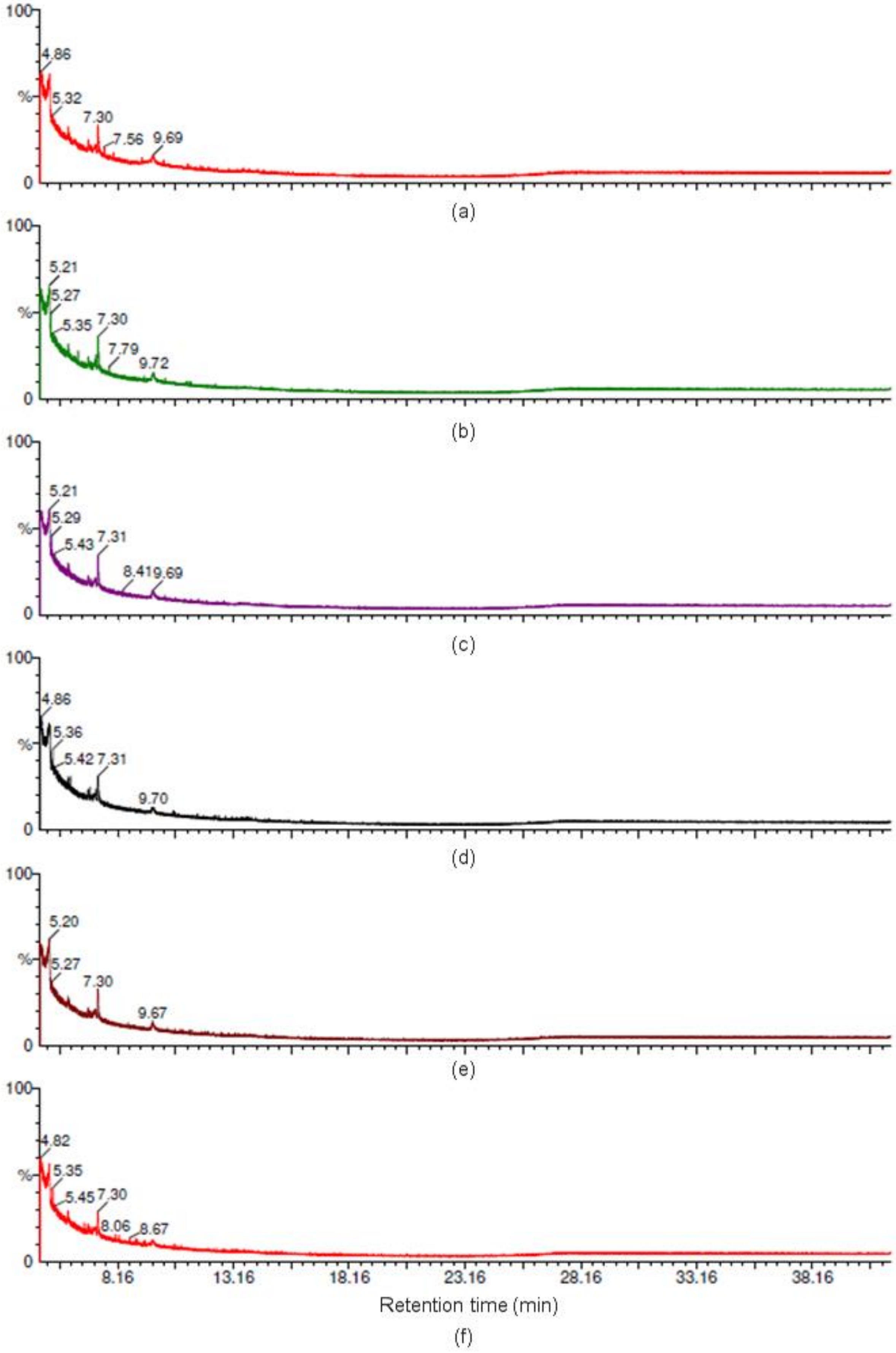
TGA was conducted using a Mattler Toledo TGA/SDTA851e. Specimens of approximately 10 mg were heated up from 40 to 250 °C at 10 °C/min, then from 250 to 550 °C at 5 °C/min to increase resolution within this region of interest, and from 550 to 850 °C at 10 °C/min. Three specimens, as dried after abrasion, per sample group were tested under N_2 atmosphere with a flow rate of 20 mL/min. Other than the abraded specimens, TGA was also performed on the constituent materials, namely C320, EVA, SBS, comingled plastic, all binders manufactured as listed in Table 3.1, and hydrated lime (HL).

4.1.3 Results

Leachability

As defined by the SQP during the initial qualitative assessment presented in Appendix A, the leachates of interest included PAHs, bisphenol-A (BPA), phthalates, styrene, and hydrocarbons, among others. The intensity peaks over retention time for all bitumen samples, as listed in Table 3.1, are presented in Figure 4.5.

Figure 4.5: Gas chromatographs for (a) ethanol blank, (b) sample B-C320, (c) sample B-C320/SBS, (d) sample B-C320/EVA, (e) sample B-C320/HDPE-PP, and (f) HDPE-PP



In Figure 4.5, peaks are identified at retention times around 5.1, 5.3, 7.3, and 9.7 minutes for all samples. These peaks are probably related to the ethanol and so it cannot conclusively be suggested that any of the analytes of interest were identified. This may suggest that:

- The analytes of interest (PAH, BPA, styrene, hydrocarbons, and phthalates) are present in concentrations below the detection limit or not present at all.
- The cold evaporation treatment is not suitable for the detection of these compounds.
- The calibration of the GC/ MS process was not appropriate for this analysis.

These findings align with those of White (2019), who also did not detect any potential contaminants of concern within the leachates following this process.

Microplastics

The gravimetric measurements as collected after each step of the bitumen dissolution and density separation process are listed in Table 4.1, considering the limitations listed in Section 4.1.2.
Sample B-C320/SBS was not analysed through this process, as quantification of bitumen separate to SBS following bitumen dissolution was not possible with the range of solvents investigated, as demonstrated in Figure 4.3.

Table 4.1: Sample gravimetric data, all samples had initial mass of 0.7500 g

Sample	Mass after bitumen dissolution (g)	Mass after density separation (g)	Bitumen content (%)
A-C320/EVA	0.7145	1.1531	4.73
A-C320/HDPE-PP (w)	0.7237	0.4463	3.51
A-C320/HDPE-PP (d)	0.7183	1.4893	4.23
A-C320	0.7473	N/A	0.36

Table 4.1 shows that for samples A-C320/EVA and A-C320/HDPE-PP (d) a mass increase following density separation was noted. This is probably due to the poor dissolution of the glycerine solution from the filters which was absorbed increasing the mass of the filter and consequently that measured following this step.

The presence of microplastics in the sample was confirmed through optical microscopy. Firstly, the bitumen (B-C320) and raw comingled plastics were put through the microscope. The acquired images are shown in Figure 4.6.

Figure 4.6: Optical microscopy images of bitumen and comingled plastics: (a) B-C320 under visible light, (b) B-C320 using a polarised lens, (c) B-C320 under UV light, (d) HDPE-PP under visible light, (e) HDPE-PP using a polarised lens, and (f) HDPE-PP under UV light

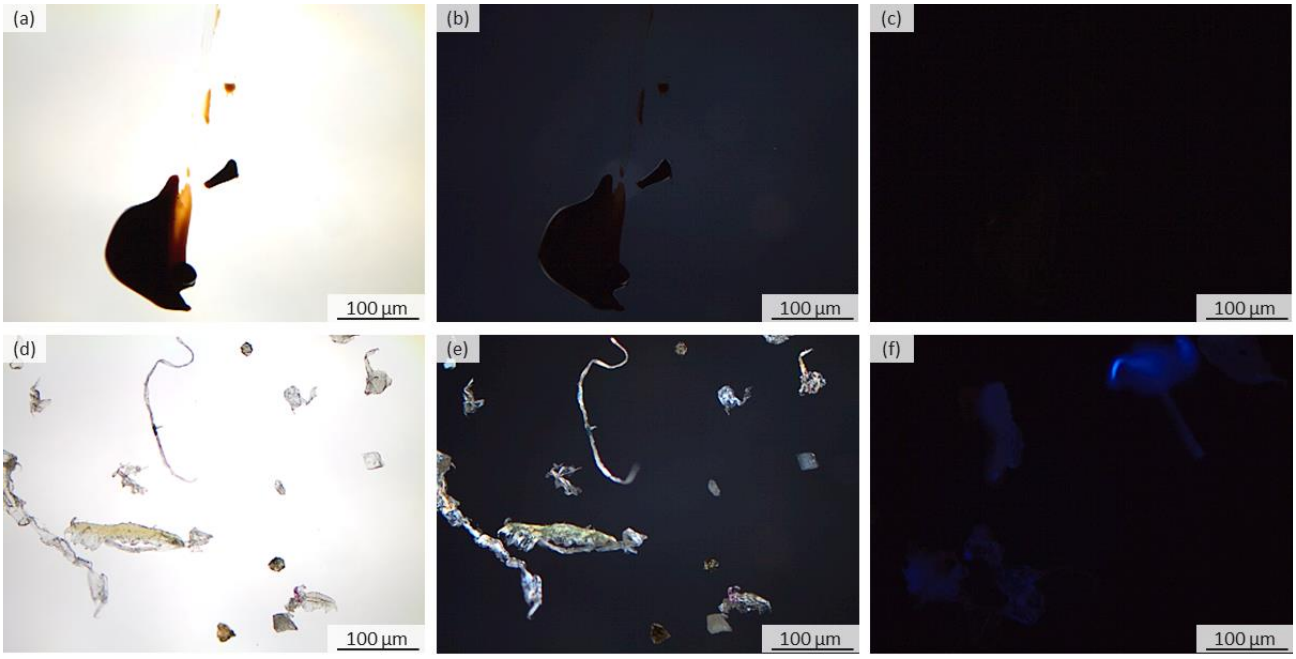


Figure 4.6 shows that bitumen appears opaque when the polarised lens was used. It might have some orange hues depending on its thickness under natural light and does not transmit any light within the UV spectrum giving a dark image with no distinctive features. On the other hand, the birefringent plastics are clearly visible when the polarised lens was used and give a blue hue under the UV light.

The acquired images from the matter collected from top surface of the glycerine suspension are shown in Figure 4.7. The black arrows indicate features visible in all images, while the red arrows indicate features visible when using the polarised lens, but not under UV light. It needs to be noted here that the visibility of features under UV light was restricted by the low resolution of the images captured. This could be resolved in a separate study by using an optical microscope with higher resolution.

Figure 4.7: Optical microscopy images of samples collected from the top surface of the glycerine suspension during density separation: (a) to (c) sample A-C320/EVA, (d) to (f) sample A-C320/HDPE-PP (w), and (g) to (i) sample A-C320/HDPE-PP (d) with (a), (d), and (g) under visible light, (b), (e), and (h) using a polarised lens, and (c), (f), and (i) under UV light

Figure 4.7 (a) shows that some aggregates remained at the top surface on the glycerine and so were inevitably collected along with the plastics by the pipette. Given that their density was expected to be notably greater than that of the glycerine used (1.25 g/mL), the fact was attributed to surface tension. The collection of light plastics through this method was confirmed by their presence in the images in Figure 4.7, however, there is no other way to confirm that all plastics were efficiently collected before the remaining matter was filtered and weighed as aggregates. Additional mass loss of particulate matter, aggregate or plastic, might also have occurred due to contact with instruments during processing.

The TGA results are presented in Table 4.2 and Figure 4.8 to Figure 4.12. A representative TGA curve for sample B-C320, the HL, the corresponding binder, and additive are presented in each of these figures. As it becomes evident from the morphology of the curves, those of the binders closely relate to the curve of the unmodified C320 bitumen but are affected by the presence of the additives. Therefore, the content of additive in the abraded sample, representing the released microplastics, was calculated based on its content in the binder. This approach assumes an even distribution of the additive in the binder. It is thought that this is a reasonable assumption given that any PMB allowed for use in asphalt has a requirement to not segregate as per ATS3110 (Austroads 2020).

Table 4.2: TGA results with content based on mass and an average of 3 tested specimens per sample

Sample ID	Mass loss (%)	Bitumen (%)	Plastic (%)	Aggregate (%)
A-C320/EVA	9.1 ± 1.7	8.5	0.6	90.9
A-C320/SBS	9.1 ± 0.2	8.5	0.6	90.9
A-C320/HDPE-PP (w)	9.0 ± 2.2	8.5	0.5	91.0
A-C320/HDPE-PP (d)	17.2 ± 2.8	5.2	12.0	82.8
A-C320	7.4 ± 0.2	7.4	0	92.6

It is evident from Table 4.2 that A-C320 was slightly less susceptible to loss of mass through abrasion while A-C320/HDPE-PP (d), which contained a significant amount of plastics, noted the greatest mass loss following abrasion. The samples made via the wet method noted similar mass loss following abrasion. The increased mass loss measured by A-C320/HDPE-PP (d) can be related to the fact that the plastic remained unmolten following mixing and behaved as aggregate. As it is less resistant to abrasion than the aggregates, it was abraded during the process and so concentrated in the sample used for analysis.

Figure 4.8 (a) shows that where a representative TGA and DTG curve for the unmodified bitumen is presented, the material is experiencing loss of mass from 218 to 765 °C. Unlike previous observations by Murugan et al. (2012) and Benbouzid and Hafsi (2008), who observed 2 peaks in the DTG curves, 3 may be found in Figure 4.8 (a). These reflect the 3 degradation stages of the bitumen, meaning that 3 different degradation rates are present. Also, unlike the findings of Murugan et al. (2012) and Benbouzid and Hafsi (2008), where approximately 20 and 35% of the bitumen remained after the process, respectively, all bitumen was degraded following TGA. Although the discrepancy with the findings of the latter can be explained by the fact that they exposed their bitumen up to 600 °C, those of the former extended beyond the 765 °C, where all bitumen was found to degrade in this research. Bitumen varies based on the source of the crude in its constitution and as a result in its properties. In addition, Murugan et al. (2012) and Benbouzid and Hafsi (2008) both demonstrated, through varying the heating rate during their TGA experiments, that the overall mass loss varies as a result. This is the result of improved heat transfer with lower heating rate (Murugan et al. 2012). Hence, these observations could potentially be attributed to the different bitumen used, different equipment, and the N_2 flow rate. A representative TGA and DTG curve of HL is given in Figure 4.8 (b) where a single degradation stage is observed between 517 and 781 °C, as observed for $CaCO_3$ by Phung et al. (2019).

Figure 4.8: Representative TGA and DTG curves for (a) B-C320, and (b) HL with the denoted figures reflecting the average of 3 specimens

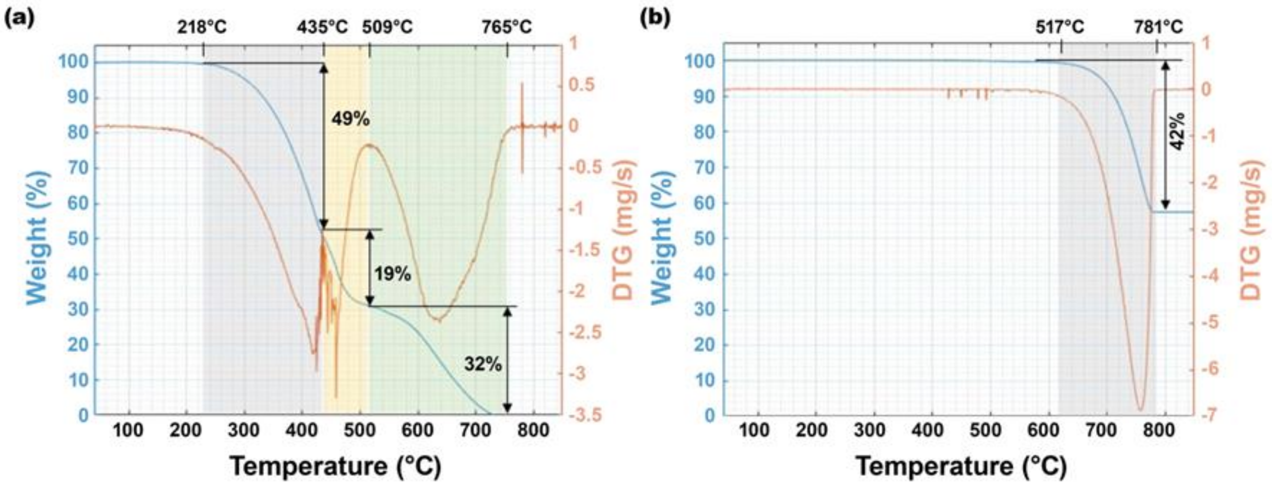


Figure 4.9 presents the results for the abraded matter from A-C320/EVA along with all constituents for comparison. The temperature range where mass loss of the abraded matter was observed to span from 188 to 837 °C, as shown in Figure 4.9 (b). The mass loss of the constituents, as presented in Figure 4.8, Figure 4.9 (c), and Figure 4.9 (d), is within this region with most overlapping.

EVA typically shows a two-step decomposition. The first stage is related to the decomposition of acetate groups, a process called deacetylation occurring between approximately 380 and 410 °C. The second stage is related to the decomposition of the main hydrocarbon chain and occurs typically at temperatures above 450 °C (Adothu et al. 2020). Figure 4.9 (c) is in line with these observations. Additionally, the incorporation of EVA in bitumen is expected to be non-reactive (Navarro et al. 2009) and hence the formation of chemical cross-links that would decompose at higher temperatures is not expected. Luo and Chen (2011) observed a shift of the temperature where the rate of decomposition is at its maximum towards higher temperatures of EVA-modified bitumen when compared to the base bitumen. This is consistent with the results in Figure 4.9, possibly confirming the presence of EVA in the analysed specimens.

Figure 4.9: Representative TGA curves for (a) EVA, HL, B-C320, B-C320/EVA, and A-C320/EVA, and representative TGA and DTG curves for (b) A-C320/EVA, (c) EVA, and (d) B-C320/EVA with the denoted figures reflecting the average of 3 specimens

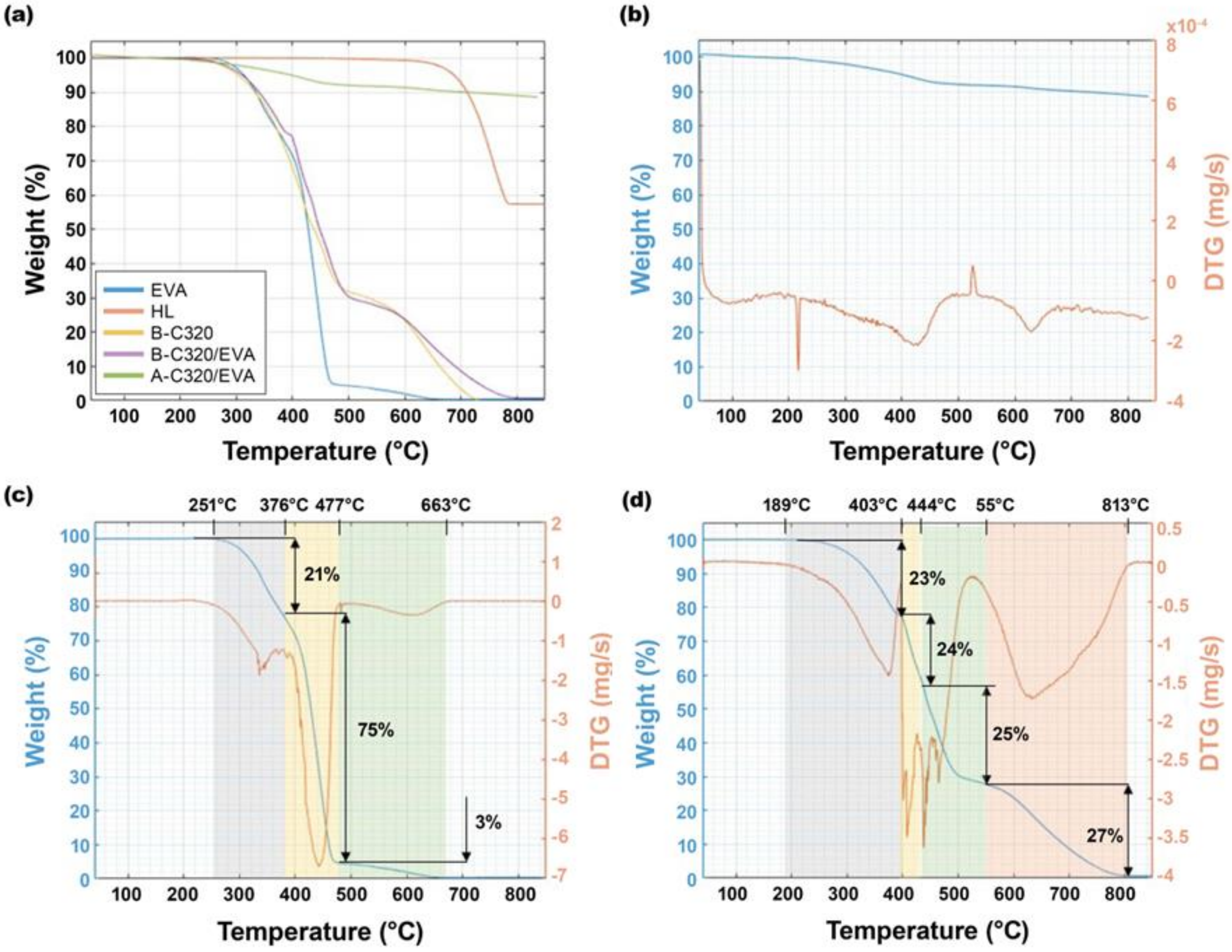


Figure 4.10 (b) shows a representative TGA and DTG curve for sample B-C320/SBS. Czajka et al. (2013) found a single decomposition step for SBS between approximately 350 and 475 °C, contradicting expectation due to the presence of both polystyrene and polybutadiene. A single decomposition step for SBS was also observed by Xu et al. (2017), who found the maximum rate of decomposition occurring around 460 °C for unaged SBS. When SBS was exposed to thermal-oxidative aging, however, a second peak at lower temperatures was found to appear, like the peak observed in Figure 4.10 (d). From the variances between the curve of the unmodified bitumen in Figure 4.8 (a) and that of B-C320/SBS in Figure 4.10 (d), it may be understood that SBS is present throughout the binder.

Figure 4.10: Representative TGA curves for (a) SBS, HL, B-C320, B-C320/SBS, and A-C320/SBS, and representative TGA and DTG curves for (b) A-C320/SBS, (c) SBS, and (d) B-C320/SBS with the denoted figures reflecting the average of 3 specimens

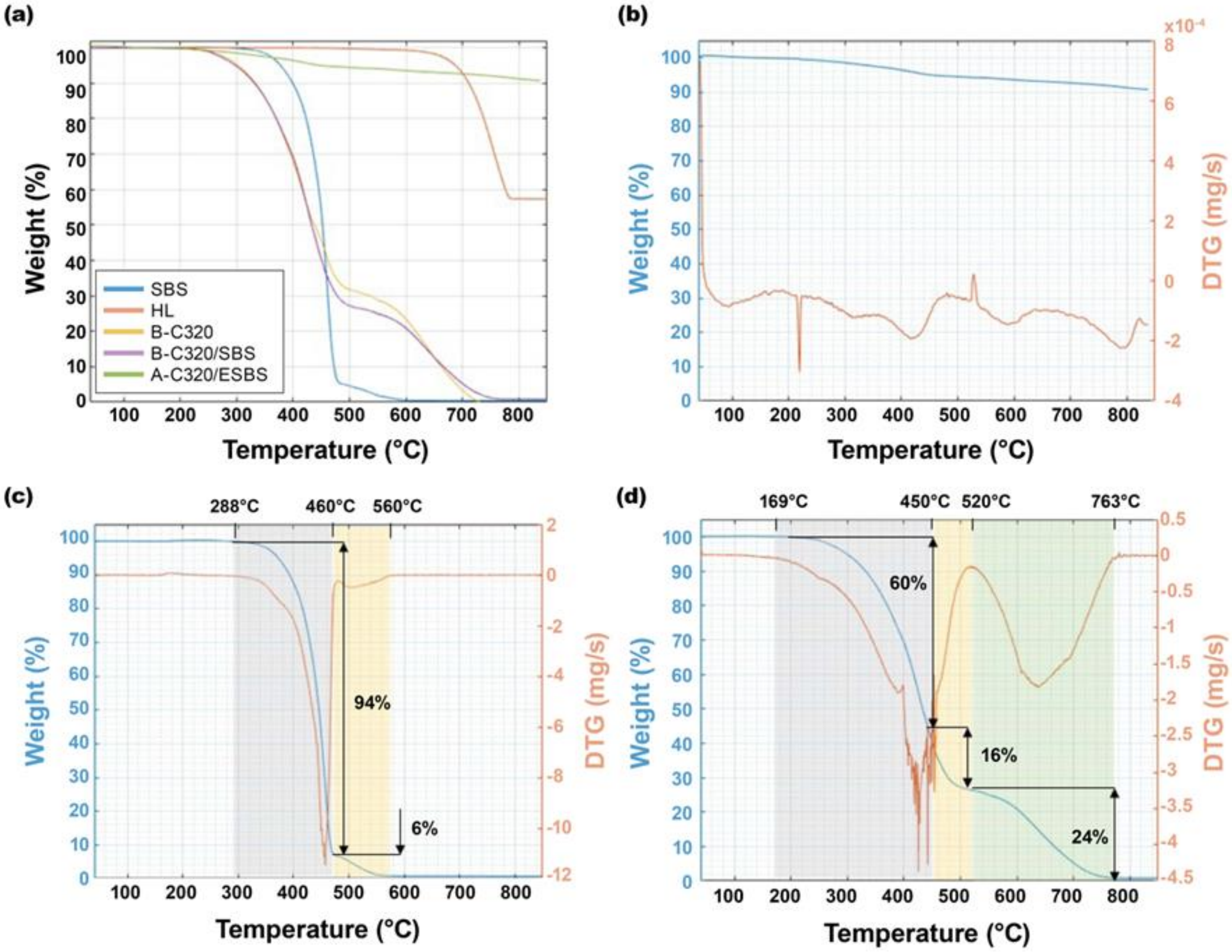
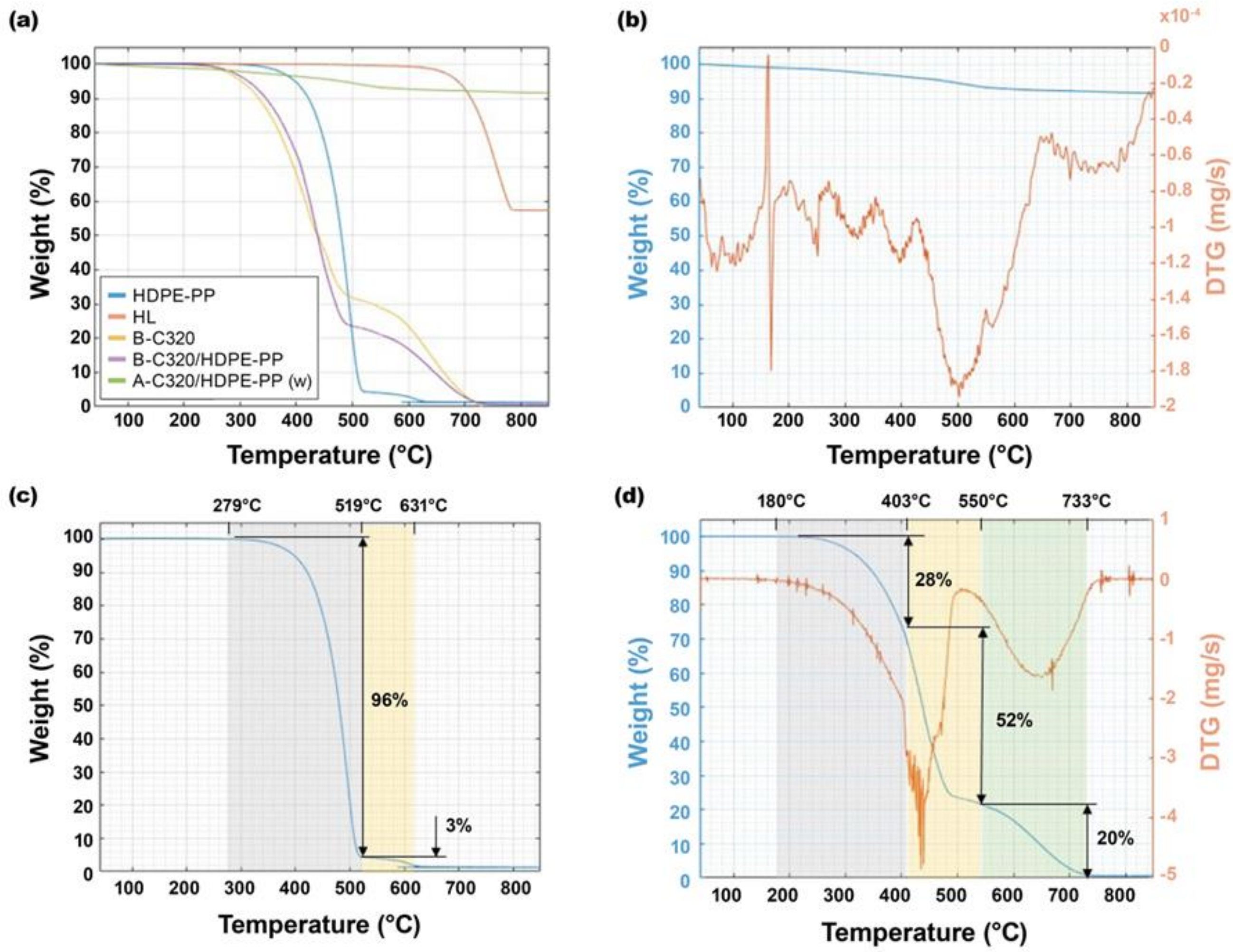


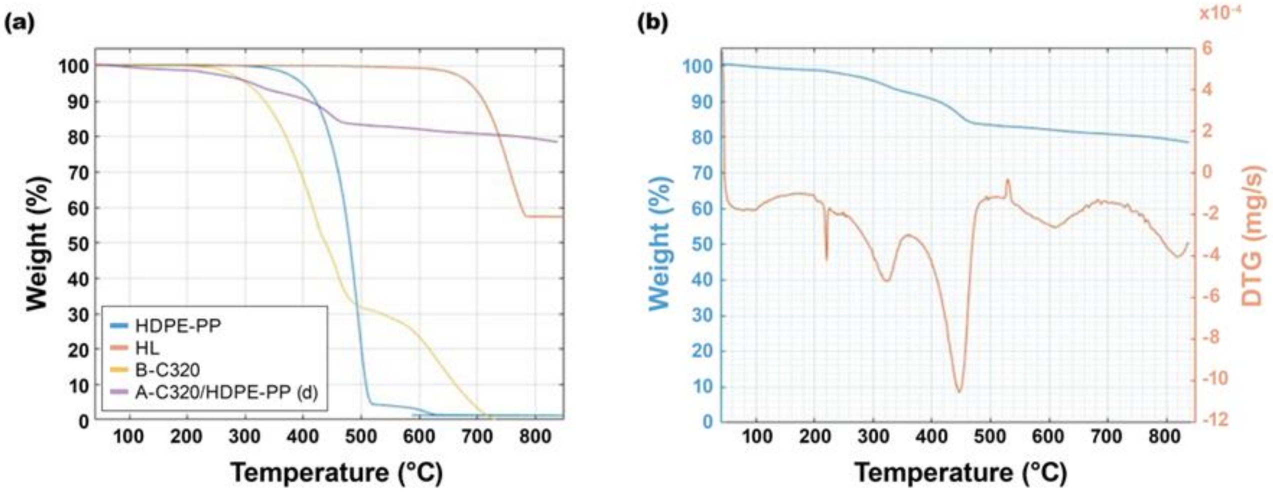
Figure 4.11 (a) reveals that the decomposition behaviour of the binder including the HDPE/PP varied when compared to that of the unmodified bitumen. This demonstrates that although the chemical modification of the bitumen is not expected, the content of HDPE/PP released following abrasion will also need to be calculated, like A-C320/EVA and A-C320/SBS. However, it needs to be noted that the DTG curve of A-C320/HDPE-PP (w) in Figure 4.11 (b) shows a distinct peak at approximately 500 °C, in line with the decomposition of HDPE/PP.

Figure 4.11: Representative TGA curves for (a) HDPE-PP, HL, B-C320, B-C320/HDPE-PP, and A-C320/HDPE-PP (w), and representative TGA and DTG curves for (b) A-C320/HDPE-PP (w), (c) HDPE-PP, and (d) B-C320/HDPE-PP with the denoted figures reflecting the average of 3 specimens



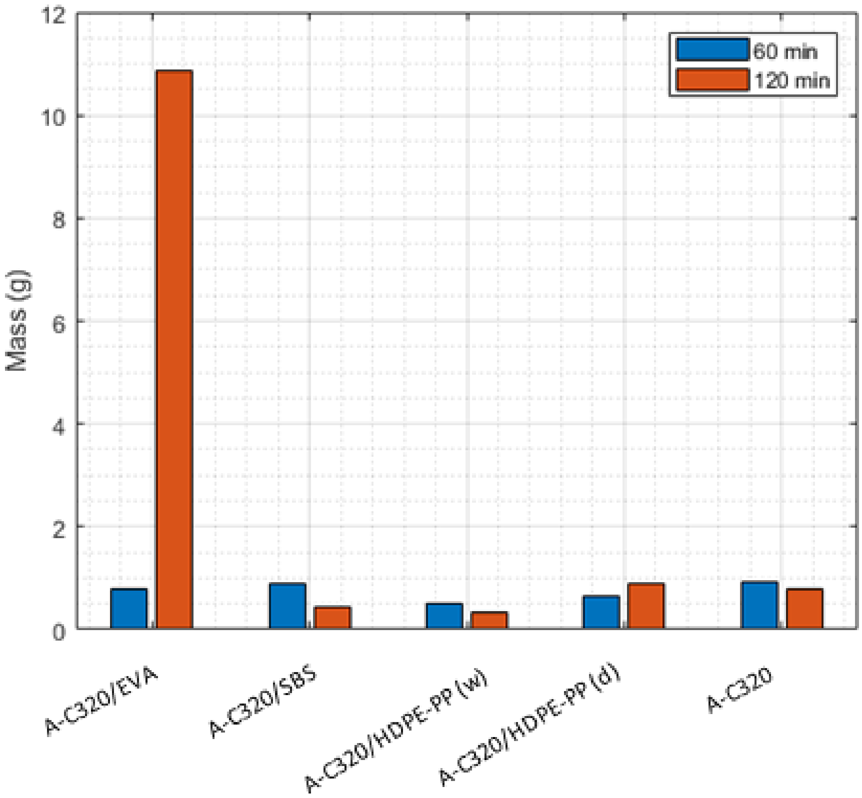
In Figure 4.12 (b), distinct regions of degradation can be observed in the temperature range where the C320 and HDPE/PP are presenting degradation. As the region within which the degradation of the comingled plastics overlaps with that of the unmodified bitumen, the content of bitumen for A-C320/HDPE-PP (d) was calculated based on the degradation of the bitumen that takes place prior to the onset of degradation of the comingled plastics. Unlike the observations from Figure 4.11 (b), the DTG curve for sample A-C320/HDPE-PP (d) presents a distinct peak as 448 °C, which may be attributed to the mass loss due to the presence of plastics in the abraded sample. Mass loss prior to that was attributed to bitumen. Between 218 and 279 °C, only bitumen is expected to have degraded allowing for the calculation of its content. It is safely assumed at this stage that the presence of plastics in the dry mix has not affected the behaviour of bitumen.

Figure 4.12: Representative TGA curves for (a) comingled plastic, HL, B-C320, and A-C320/HDPE-PP (d) and (b) representative TGA and DTG curves for A-C320/HDPE-PP (d)



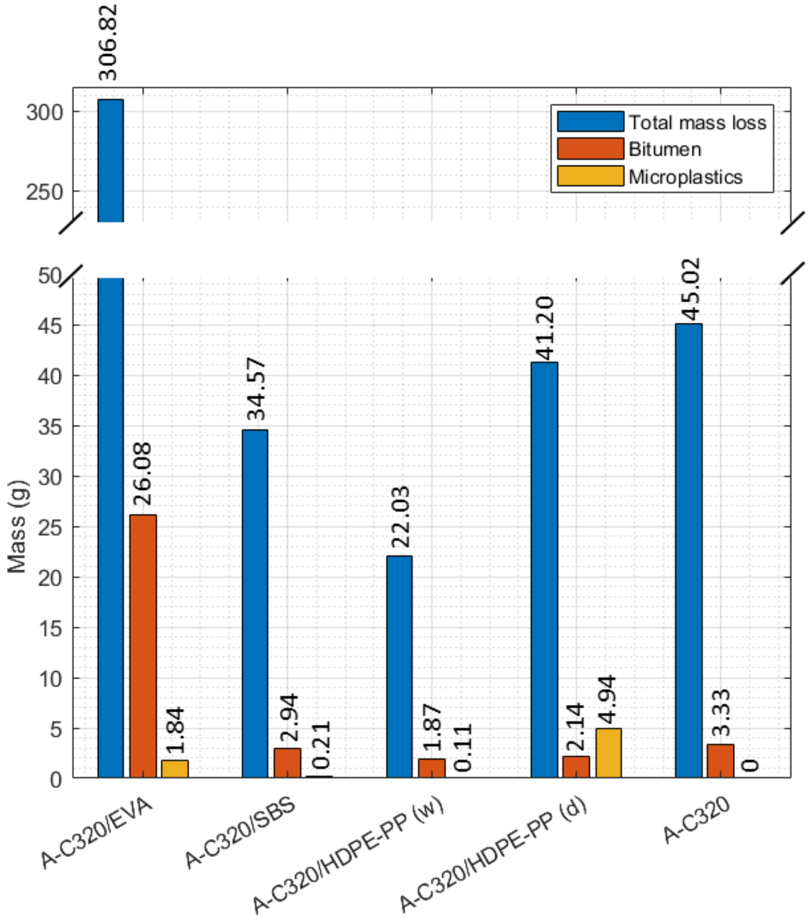
The overall mass of residues released after 60 and 120 minutes of abrasion is summarised in Figure 4.13. It shows that the behaviour of the slabs was not consistent with A-C320/EVA and A-C320/HDPE-PP (d) releasing more particulate matter within the second hour of abrasion, while the opposite was true for the rest.

Figure 4.13: Particulate matter release after the first hour and after the second hour of abrasion with the AMAT



The mass released of each of the constituents for an area of 1 m^2 was calculated from the contents of each constituent (bitumen, aggregates, and microplastics), as calculated in Table 4.1 and Table 4.2, and the mass of particulates released following abrasion for 120 min. These calculations were undertaken based on the surface abraded using the AMAT, which was 0.038 m^2. These calculations are presented in Figure 4.14.

Figure 4.14: Averaged mass of bitumen and microplastics released after 120 minutes of abrasion over 1 m^2 of asphalt, as derived from TGA



A notably greater amount of particulate matter was released from slab A-C320/EVA, which is discussed in Section 4.1.4 following visual evaluation of the slab's surface. Due to the greater amount of particulates released for slab A-C320/EVA, even though the content of microplastics was found to be comparable to that of A-C320/SBS and A-C320/HDPE-PP (w), when calculated as mass of microplastics released over 1 m^2, its content is found to be greater.

4.1.4 Discussion and Recommendations

Leachability

Leaching of compounds harmful to the environment needs to be taken into consideration when investigating the incorporation of waste materials in applications where they may be directly interacting with the aquatic environment. Other than the method proposed by White (2019), no other method has been developed for the efficient quantification of leachates by asphalt. Based on the results of this research, adding various polymeric materials in bitumen did not release any compounds harmful to the environment. However, even though the results of analytical methods such as GC/MS may be trusted for this analysis, the method through which the samples were prepared may be modified for more aggressive exposure to be achieved.

Thayumanavan et al. (2003), who also investigated the leachability of asphalt materials, prepared their waste material solid samples by vigorously shaking in distilled water (4 parts liquid) at 24 ± 2 °C for 24 hours for short-term leaching and 168 hours for long-term leaching. They concluded that if leachates are not observed following this preparation method, they are unlikely to be present. This may be an approach to be investigated in future analysis; however, if the method followed to dry the liquid phase is not compatible, the results may once again be inconclusive.

Microplastics

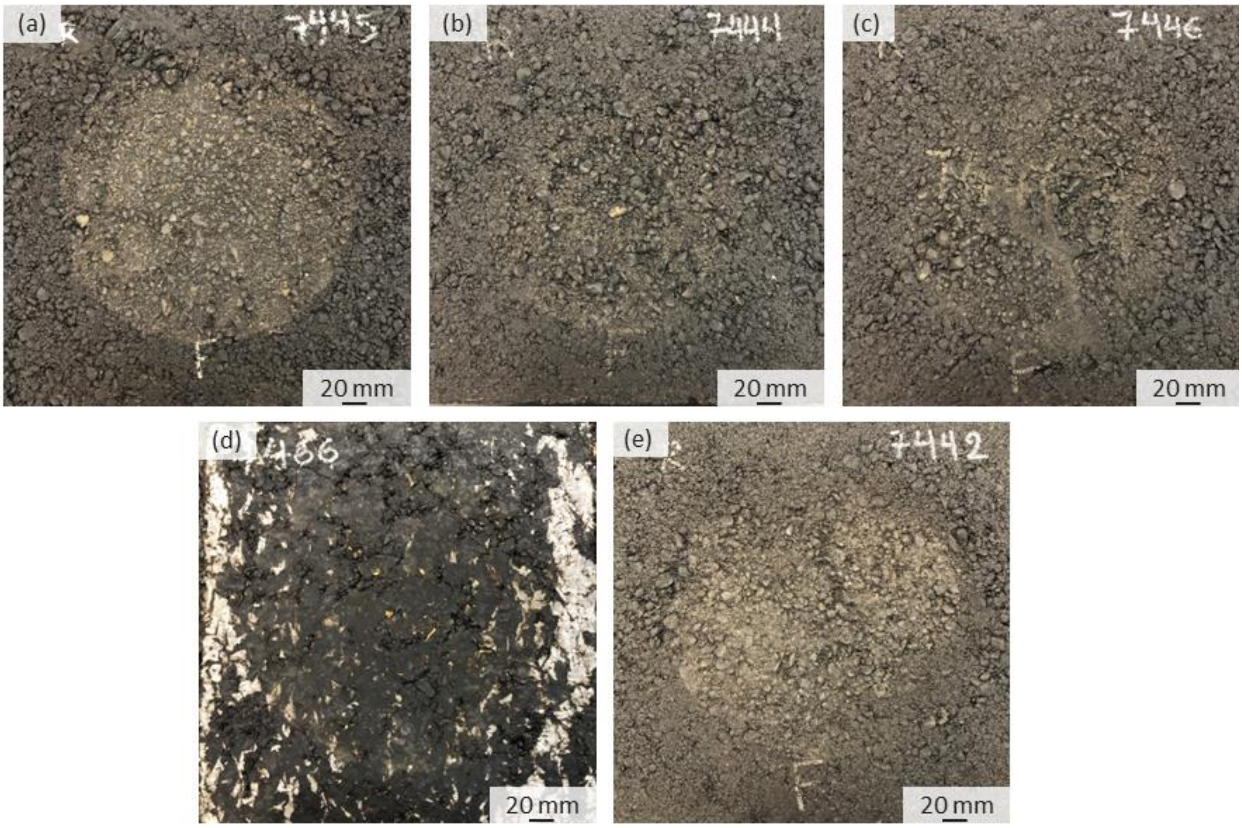
Most of the mass of the abraded samples was comprised of aggregates. It needs to be noted here that this observation is also related to their greater density and not only their quantity. This was true for both methods of measurement. It is still expected though that the concentration of aggregates would be greater than that of bitumen and/or plastics. Similar observations were made by Austroads (2022a) who justified the phenomenon by the formation of a thin binder film at the surface of the asphalt slab, which once abraded exposes the larger aggregates.

From the gravimetric data acquired through the process of bitumen dissolution and density separation of the aggregates from the microplastics, the particulate matter released was primarily comprised of aggregates, but the quantification of bitumen and plastics was not reliable. Other than the outlined limitations of the experimental methodology which were taken into consideration throughout, the probable absorption of the glycerine solution by the filter and the high surface tension of some aggregate particles which were not submerged in glycerine as expected led to unreliable measurements of the constituents. In future, the use of a different filter that would not be as prone to absorbing the selected solution or a different solution choice might resolve these issues but could not be recommended with confidence without further testing.

Overall, from the TGA analysis, it may be understood that the incorporation of comingled plastics in asphalt through the dry process is more susceptible to releasing microplastics. This is not only related to the probably weak interface between bitumen and the comingled plastics, but also due to the significantly greater amount of plastics present in A-C320/HDPE-PP (d).

Additionally, the less textured surface of the slab A-C320/HDPE-PP (d), shown in Figure 4.15 (d), resulted in a greater contact surface between the abrading head and the bitumen and plastics content of the asphalt slab. The most pronounced discolouration following abrasion may be seen in Figure 4.15 (a) for sample A-C320/EVA, which released the greatest mass of particulate matter following abrasion for 120 min. From Figure 4.13, it may be seen that most of that matter was released during the second hour of abrasion.

Figure 4.15: Surface of abraded slabs after 120 min: (a) A-C320/EVA, (b) A-C320/SBS, (c) A-C320/HDPE-PP (w), (d) A-C320/HDPE-PP (d), and (e) A-C320



Additionally, more bitumen was released following abrasion of slabs made using PMBs when compared to the slab made using unmodified bitumen. This could be related to the thickness of the formed film on the surface of the aggregates affected by the viscosity of the binder. It is generally found that the addition of polymers in bitumen results in an increase in the viscosity when compared to unmodified bitumen (Behnood & Gharehveran 2019), which may in turn negatively affect the efficiency of the aggregate coating making it uneven, possibly explaining this observation. Additionally, with the exception of sample A-C320/HDPE-PP (d), which was fabricated through the dry method, the content of released microplastics was less than that of bitumen, in agreement with the findings of Austroads (2022a) for samples generated through the wet method.

Comparing the 2 different methods for quantification, one being the collection of gravimetric data before and after bitumen dissolution and density separation and the other being TGA, the former was found to come with a series of limitations including those listed in Section 4.1.2 and observations from the results of Section 4.1.3. As a result, there is no confidence that an accurate measurement for the content of the different constituents can be achieved. On the other hand, TGA is a more accurate method for quantification restricted mainly by the size of the specimens. Other hurdles that were part of the interpretation of the results, as discussed in Section 4.1.3, may be overcome by TGA analysis of the raw materials, which was not conducted as part of this preliminary study, but is recommended for future analysis.

4.2 Part B: Assessment of Selected Plastics Through Developed Monitoring Protocol

4.2.1 Materials

The materials used for this component of the research are the binders and the slabs as listed in Table 3.2. Asphalt slabs of 305 x 305 x 50 mm^3 were prepared using C170 bitumen and different additives as listed. These slabs were prepared using the wet and dry method and are henceforth referred to by their allocated naming conventions. Following manufacture, the asphalt slabs were conditioned for 120 ± 0.5 hours in an air forced oven at 85 ± 3 °C, as per AASHTO R30-02 (AASHTO 2015) prior to abrasion as described in Appendix F.3. This was to simulate abrasion following ageing due to exposure to the environment.

4.2.2 Methodology

The methods for examining the release of leachates and microplastics was developed from the findings from Part A and the report provided by SQP, included in Appendix C.

Leachability

As the analytes of interest were not detected following the methodology described in Section 4.1.2, it was decided that, for Part B, the method was to be altered. In addition, from the SQP comments and advice, it was derived that a standard leachate testing method (typically used for soil samples), ASLP (Australian Standard Leach Procedure, AS 4439.2 and 4439.3) should be investigated. The method is typically used for quantifying leachates in soils.

Loose asphalt mix samples were collected at the ARRB laboratory and sent to the Australian Laboratory Services (ALS) for ASLP analysis. Samples from all asphalt mixes listed in Table 3.2 were investigated with 350 g of the loose asphalt mix collected in specialty glass containers supplied by ALS. The parameters for investigation are listed in Table 4.3. Samples were prepared following AS 4439.2 and AS 4439.3.

Table 4.3: Analytical methods for loose asphalt mixes; all asphalt mixes were examined for all parameters listed

Parameter	Method	Limit of reporting
Total metals by ICP/MS (including digestion)	US EPA 6020	0.01 mg/L
VOC – MAHs	US EPA 8260	1–5 µg/L
SIM – PAH only	US EPA 8270	0.5–1 µg/L
SVOC – Phthalate esters	US EPA 8270	2–10 µg/L
Phenolics and other polar compounds (including bisphenol-A)	LC/MSMS (in-house)	0.05 µg/L
8 metals (total)	US EPA 6020, APHA 3112 – Hg B	0.0001–0.005 mg/L
TPH/BTEXN	US EPA 8015, US EPA 8260	1–100 µg/L

A brief description for the sample preparation and examination methods is provided in Table 4.4.

Table 4.4: Brief method summaries and sample preparation

Analytical method		Reference to	Method description
EG005W	Water leachable metals by ICPAES	US EPA SW 846-6010, APHA 3120	The ICPAES technique ionises leachate sample atoms emitting a characteristic spectrum. This spectrum is then compared against matrix matched standards for quantification. This method is compliant with NEPM schedule B (3).
EG035W	Water leachable mercury by FIMS	APHA 3112 Hg-B	Flow-injection ($SnCl_2$) (cold vapour generation) AAS (FIM-AAS) is an automated flameless atomic absorption technique. A bromate/bromide reagent is used to oxidise any organic mercury compounds in the TCLP solution. The ionic mercury is reduced online to atomic mercury vapour by $SnCl_2$ which is then purged into a heated quartz cell. Quantification is by comparing absorbance against a calibration curve. This method is compliant with NEPM schedule B (3).
EP071	TRH – semivolatile fraction	US EPA SW 846-8015	The sample extract is analysed by capillary GC/FID and quantification is by comparison against an established 5-point calibration curve of n-alkane standards. This method is compliant with the QC requirements of NEPM schedule B (3).
EP074	VOC	US EPA SW 846-8260	Water samples are directly purged prior to analysis by capillary GC/MS and quantification is by comparison against an established 5-point calibration curve. This method is compliant with NEPM schedule B (3).
EP075	Semivolatile organic compounds	US EPA SW 846-8270	Sample extracts are analysed by capillary GC/MS and quantification is by comparison against an established 5-point calibration curve. This method is compliant with NEPM schedule B (3).
EP075 (SIM)	PAH/phenols (GC/MS – SIM)	US EPA SW 846-8270	Sample extracts are analysed by capillary GC/MS in SIM mode and quantification is by comparison against an established 5-point calibration curve. This method is compliant with NEPM schedule B (3).
EP080	TRH volatiles/BTEX	US EPA SW 846-8260	Water samples are directly purged prior to analysis by capillary GC/MS and quantification is by comparison against an established 5-point calibration curve. Alternatively, a sample is equilibrated in a headspace vial and a portion of the headspace determined by GC/MS analysis. This method is compliant with the QC requirements of NEPM schedule B (3).
EP247	Phenolics and other polar compounds by LC/MSMS	–	LC/MSMS, direct injection. A sample is filtered and injected directly onto the LC/MSMS. Analysis is by LC/MSMS, ESI negative mode.
Preparation method		**Reference to**	**Method description**
EN25W	Digestion for total recoverable metals in DI water leachate	US EPA SW 846-3005	Method 3005 is a nitric/hydrochloric acid digestion procedure used to prepare surface and ground water samples for analysis by ICPAES or ICPMS. This method is compliant with NEPM schedule B (3).
EN60-Dla-G	Deionised water leach – glass leaching vessel	AS 4439.3	QWI-EN/60 preparation of leachates.
EN60Z-Dla	Deionised water leach – zero headspace extraction	AS 4439.2	QWI-EN/60 preparation of leachates.

Notes:

- EP075 (SIM) and EP075 – Where reported, benzo(a)pyrene toxicity equivalent quotient (TEQ) per NEPM (2013) is the sum total of the concentration of 8 carcinogenic PAHs multiplied by their toxicity equivalence factor (TEF) relative to benzo(a)pyrene. TEF values are provided in brackets as follows: benz(a)anthracene (0.1), chrysene (0.01), benzo(b+j) & benzo(k)fluoranthene (0.1), benzo(a)pyrene (1.0), Indeno(1.2.3.cd)pyrene (0.1), dibenz(a.h)anthracene (1.0), benzo(g.h.i)perylene (0.01). Less than LOR results for 'TEQ zero' are treated as zero.
- EP080 – Where reported, total xylenes is the sum of the reported concentrations of m&p-xylene and o-xylene at or above LOR.
- EP074 – Where reported, total trihalomethanes is the sum of the reported concentrations of all trihalomethanes at or above the LOR.
- EP074 – Where reported, total trimethylbenzenes is the sum of the reported concentrations of 1.2.3-trimethylbenzene, 1.2.4-trimethylbenzene and 1.3.5-trimethylbenzene at or above the LOR.
- EP075 (SIM) – Where reported, total cresol is the sum of the reported concentrations of 2-methylphenol and 3- & 4-methylphenol at or above the LOR.
- EP075 – Where reported, 'Sum of PAH' is the sum of the USEPA 16 priority PAHs.

To further explore the method described in Section 4.1.2, it was decided that the samples were to be exposed more aggressively prior to leaching assessment through GC/MS. Taking into consideration the agitation proposed by Thayumanavan et al. (2003), the sample preparation was altered as follows:

- An amount of 2.5 g of each binder listed in Table 3.2 as well as the as-received HDPE/PP and LDPE were placed in glass beakers and submerged in 50 mL of deionised water.

- The glass beakers were covered with aluminium foil and the samples were agitated using a magnetic stirrer for 1 hour under ambient temperature.
- They were then placed in an air forced heating oven at 40 °C for 18 hours.
- The samples were agitated again using a magnetic stirrer for another 1 hour under ambient temperature.
- After exposure, the potentially contaminated water was filtered through a 4 µm mesh filter and collected in a glass container.
- The water was then cold evaporated under N_2 atmosphere, and the residue was submerged in 5 mL of ethanol (Merck, spectroscopy grade) for GC/MS.

It needs to be noted that to understand the effects of agitation, the parameters for analysis during GC/MS were kept the same as Part A.

Microplastics

For the collection of particulate matter from the slabs, the same abrasion method as described in Appendix F.3 was used. The water was evaporated before the solid abraded matter could be collected in a dehydration oven set to 60 °C. Following the recommendations from Section 4.1.4, TGA was selected for the analysis of the particulate matter following the same equipment and parameters as detailed in Section 4.1.2.

4.2.3 Results and Discussion

Leachability

The report on the ASLP results, as provided by ALS, is included in Appendix D. The report provides results for various analytes, however, in this section, only those that gave readings above the limit of reporting (LOR) are discussed for comparison. The LOR for each of the analytes is clearly marked in the charts. Although all samples are listed across the x-axis, where a value is not provided the measurements were below the LOR.

Figure 4.16 provides a quantification of the PAH measured. Although all 16 priority analytes were investigated (see page 5 of 15 in Appendix D.1), only naphthalene was detected above the LOR for samples A-C170 and A-C170/ EVA with the latter measured at greater concentration. Naphthalene was not detected to have leached from the specimens containing the recycled plastics incorporated for the purposes of this study. The ‘Sum of PAH’ is comprised by the measured naphthalene.

From National Environment Protection Council (2013) (Table 1C), the groundwater investigation level (meaning the levels above which further investigations need to be undertaken) for naphthalene is 16 µg/L for fresh waters and 50 µg/L for marine waters. Any measured naphthalene from the loose asphalt mixes investigated in this project is well below either of these limits, as shown in Figure 4.16 and Appendix D.1.

Figure 4.16: Naphthalene concentration following leachability assessment for PAH of loose mix asphalt

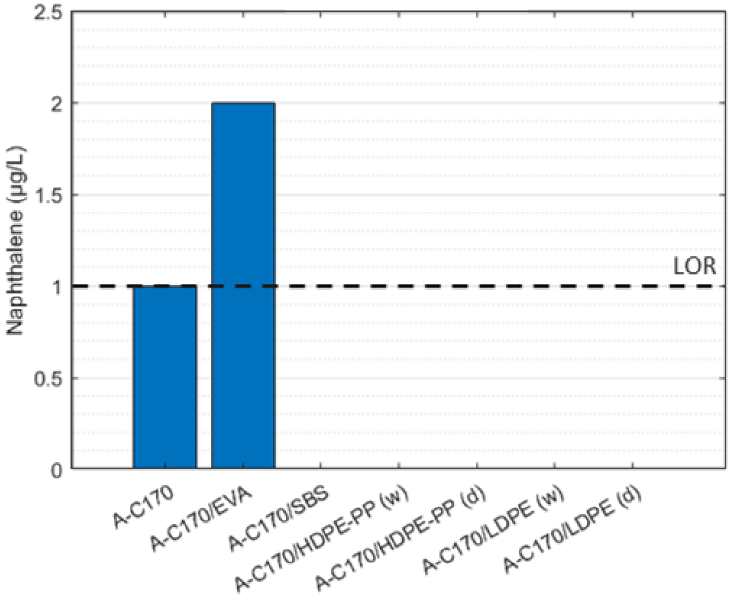
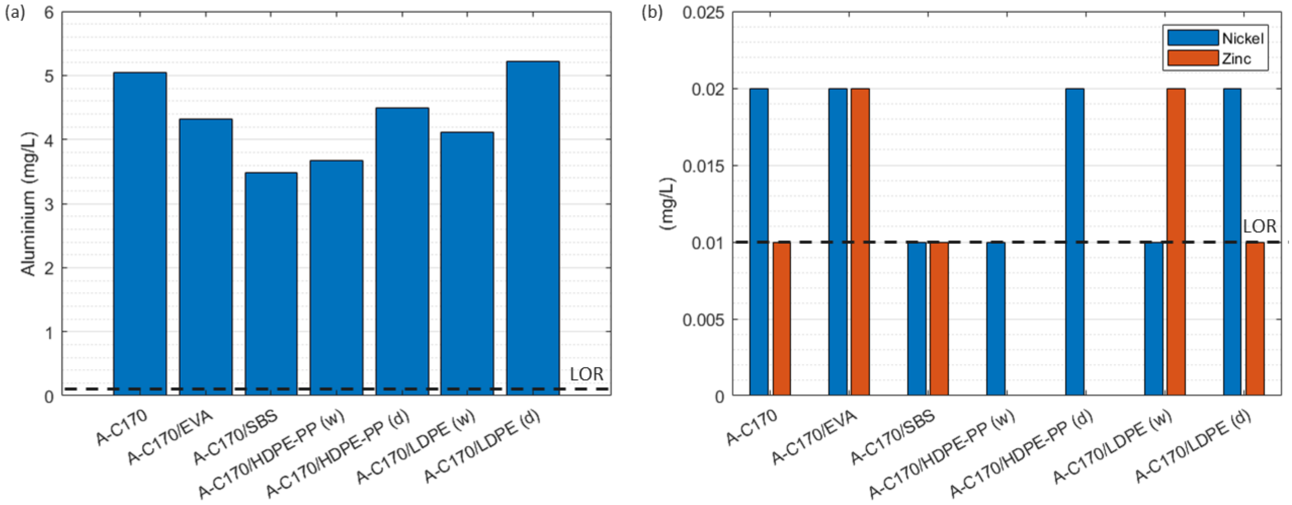


Figure 4.17 presents the measured water leachable metals in the loose mix asphalt. Aluminium and nickel were measured for all samples, and most were found to release zinc, except for samples containing HDPE/PP incorporated either via the wet or the dry method. When compared to the baseline (A-C170, A-C170/EVA, and A-C170/SBS), only A-C170/LDPE (d) was found to leach a greater amount of aluminium and A-C170/LDPE (w) leached a greater amount of zinc.

From National Environment Protection Council (2013) (Table 1C), the ground-water investigation level for aluminium is 55 µg/L for fresh waters. For nickel it is 11 µg/L for fresh waters, 7 µg/L for marine waters, and 0.02 mg/L for drinking waters. For zinc it is 8 µg/L for fresh waters and 15 µg/L for marine waters. The measured aluminium for all samples exceeds the ground-water investigation limit for drinking water as set by National Environment Protection Council (2013). The ground- water investigation level for nickel for marine waters and for zinc for fresh waters is below the LOR. Therefore, there is uncertainty as to whether the zinc that potentially leached from samples A-C170/HDPE-PP (w) and A-C170/HDPE-PP (d) was below or beyond the level of investigation. In addition, the LOR for both nickel and zinc is 0.01 mg/L. As such, the data acquired do not introduce enough granularity to confidently conclude that they are just above, at, or below the investigation level for nickel for fresh water for samples A-C170/SBS, A-C170-HDPE-PP (w), and A-C170/LDPE (w) and for zinc for marine waters for samples A-C170, A-C170/SBS, and A-C170/LDPE (d). The measured nickel for A-C170, A-C170/EVA, A-C170/HDPE-PP (d), and A-C170/LDPE (d) was above the fresh waters and marine waters ground-water investigation level and at the drinking waters limit. Lastly, the measured zinc for A-C170/EVA and A-C170/LDPE (w) was also above the ground-water investigation level.

Figure 4.17: Concentration of water leachable metals in loose mix asphalt



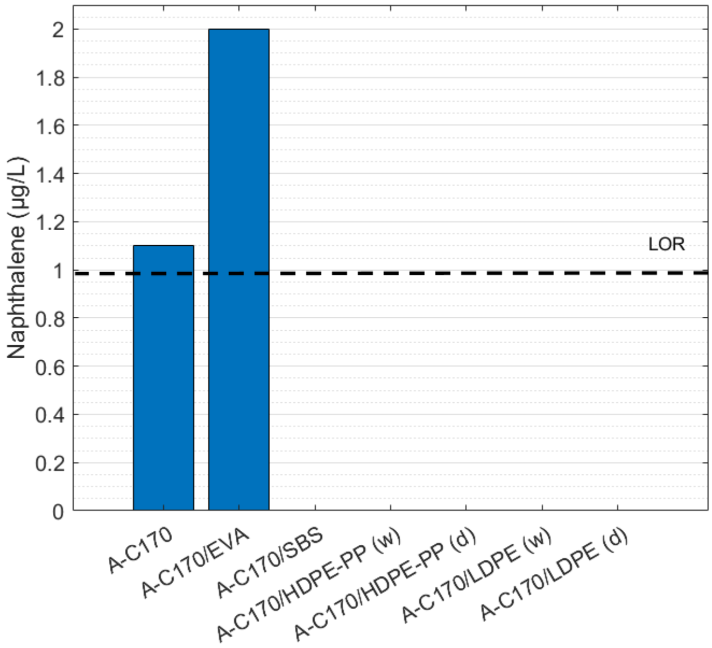
According to the National Environment Protection Council (2013), the presence of metals may be associated with ore bodies within the proximity of mining or quarrying activities. Given the comparable levels of the leachates among the various samples investigated in this study, it may be proposed that the water leachable metals measured are due to the aggregates in the loose mix asphalt rather than the bitumen or any of the polymeric additives. However, Xu and Zhang (2020) previously discussed that, among others, nickel is one of the heavy metals that may be found in crude oil.

Other analyte groups including phthalate esters, total petroleum hydrocarbons, total recoverable hydrocarbons, phenolics and related hydrocarbons, monocyclic aromatic hydrocarbons, as well as BTEXN were also analysed but all results obtained were below the LOR.

The ASLP results following the crushing of the loose asphalt mix showed leaching of metals, which was thought to be relating to quarry activities. Therefore, the analysis was repeated without crushing the loose asphalt mix prior to testing. The loose asphalt mix was sieved to pass 9.5 mm.

Naphthalene was the only PAH detected, similar to what was observed by the results obtained by the crushed aggregates. These measurements are presented in Figure 4.18. As in the case of crushed loose asphalt mix, the only samples for which naphthalene was detected were A-C170 and A-C170/EVA. Both demonstrated the same trend, with A-C170/EVA leaching a greater amount when compared to A-C170, both of which were notably below the ground-water investigation limits set by National Environment Protection Council (2013). Brandt and De Groot (2001) also found naphthalene to be detected at notably greater concentrations when compared to other PAHs. This was potentially due to the fact that naphthalene is comprised by 2 fused benzene rings, meaning that it has greater solubility in water (PAHs with 4 or less rings).

Figure 4.18: Naphthalene concentration following leachability assessment for PAH of loose mix asphalt (uncrushed)

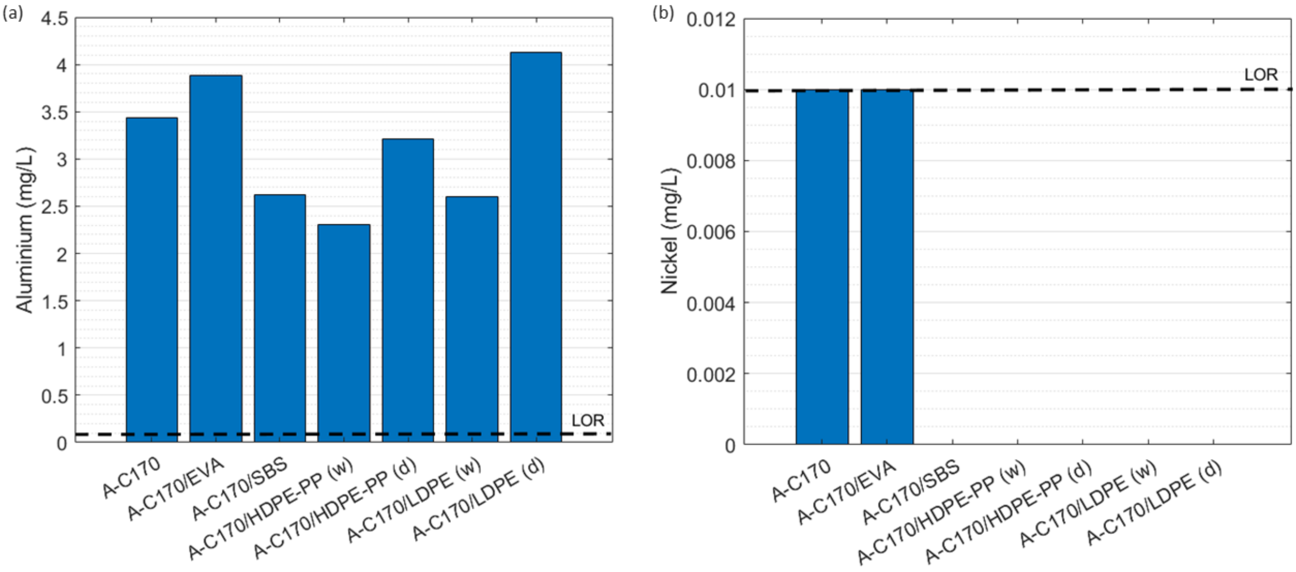


Irrespective of the fact that for this examination the loose asphalt mix was not crushed and, therefore, the aggregates were thought to not have been exposed to the analysis, leachable metals were still detected. These results are presented in Figure 4.19. Zinc was not detected for the uncrushed loose mix asphalt, but as for the crushed samples, the uncrushed ones were found to leach aluminium and nickel.

Aluminium continues to be above the ground-water investigation level for fresh waters, as measured for all samples, therefore, further studies would be recommended for all. When compared to those of the crushed specimens, the uncrushed specimens were measured to leach less amounts of aluminium. When compared to commonly accepted materials, only A-C170/LDPE (d) was found to leach greater concentrations of aluminium, but not notably above those of A-C170/EVA.

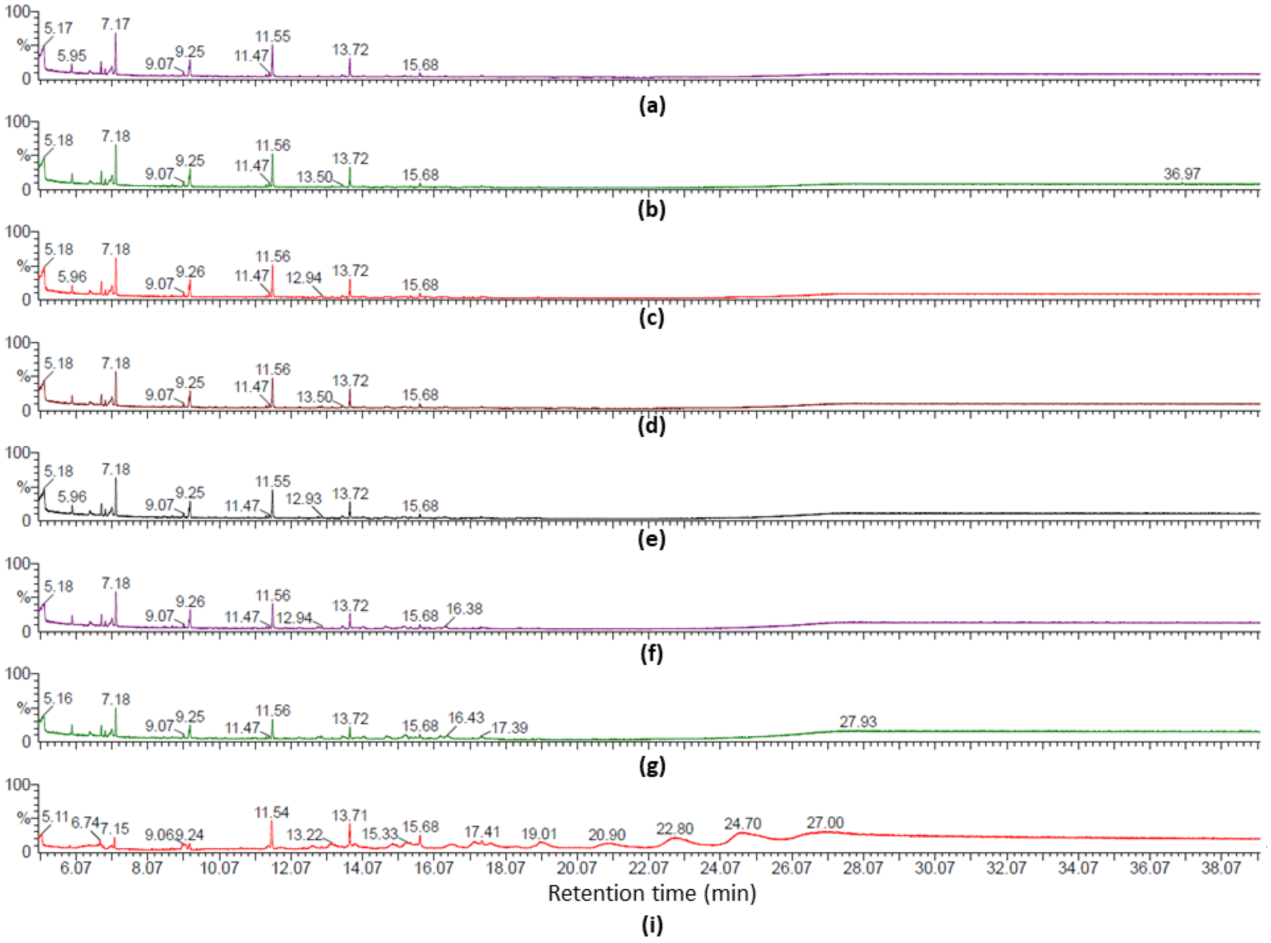
Nickel was present in A-C170 and A-C170/EVA samples. Nickel was measured at 10 µg/L, which is above the ground-water investigation limit for marine waters according to National Environment Protection Council (2013). As the presence of nickel persists following assessment without crushing the loose mix asphalt, it may be considered that it is leached by the binder, as previously discussed by Xu and Zhang (2020).

Figure 4.19: Concentration of water leachable metals for uncrushed loose mix asphalt



The results obtained from the GC/MS analysis are presented in Figure 4.20.

Figure 4.20: GC-MS peaks: (a) B-C170/SBS, (b) LDPE, (c) B-C170/ LDPE, (d) B-C170/ HDPE-PP, (e) B-C170/EVA, (f) B-C170, (g) HDPE/PP, (i) ethanol



All the peaks present in Figure 4.20, as for Part A, can be associated with the ethanol which was the selected carrier liquid. The peak associated with siloxane in Figure 4.20 (b), was attributed to contamination in the column. Therefore, the processing method during GC/ MS as well as the sample preparation selected may not be suitable to assess the release of leachates from bituminous binders.

As the sample preparation was quite elaborate, it is recommended that in future the analysis method through GC/MS is developed further. This would include selecting specific compounds of interest and calibrating the method accordingly. This is an elaborate effort but would allow for the specification of low limits of detection for the compounds and whether they can be detected at all. In this form, it would provide a more quantitative image of the findings.

Microplastics

The constitution of the particulate matter from abrasion, as measured through TGA, is quantified in Table 4.5 and the TGA and DTG curves are presented in Figure 4.21 to Figure 4.28. Like the binders created using C320, the C170 modified binders also closely related to the B-C170 with small shifts in the TGA curves, particularly around 450 °C, where the unmodified bitumen marks a greater mass loss than the binders. Therefore, as in Section 4.1.3, the released microplastics were calculated based on the content of the additive in the binder. However, as the bitumen is not expected to have been modified by the additive where the modification took place through the dry method, the content of microplastics for A-C170/HDPE-PP (d) and A-C170/LDPE (d) was measured through the mass loss in the region of the degradation of the polymer. Mass loss below 200 °C was attributed to moisture that failed to evaporate during the oven drying process, given the lower temperature used during drying for Part B.

Table 4.5: TGA results with content based on mass and average of 3 tested specimens per sample

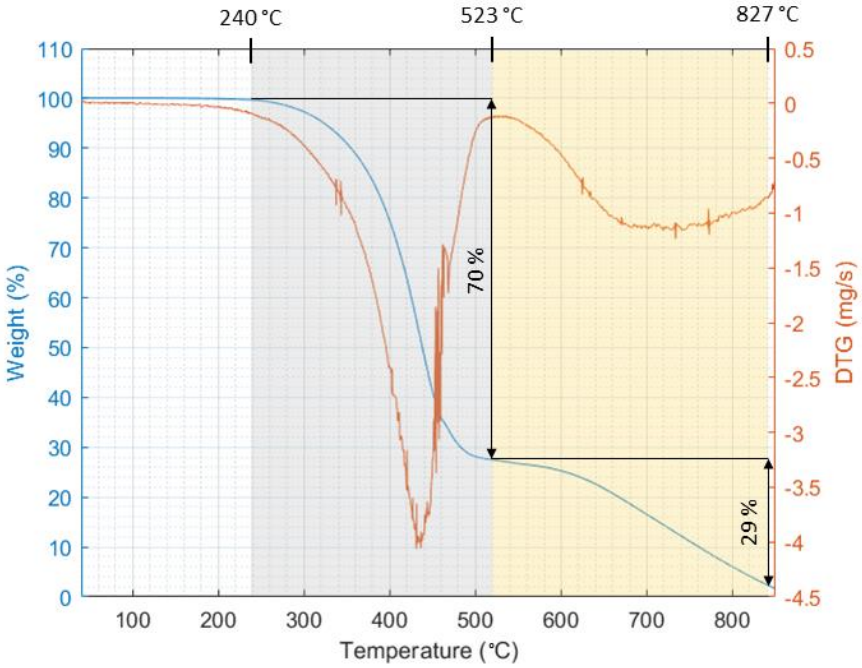
Sample ID	Total mass loss (%)	Mass loss below 200 °C (%)	Bitumen (%)	Plastic (%)	Aggregate (%)
A-C170	14.2 ± 0.6	1.6 ± 0.1	12.6	0	85.8
A-C170/EVA	10.7 ± 0.5	3.3 ± 0.4	7.4	0.4	89.3
A-C170/SBS	9.3 ± 1.6	3.0 ± 0.4	6.3	0.4	90.7
A-C170/HDPE-PP (w)	11.1 ± 1.4	1.9 ± 0.4	8.3	0.9	88.9
A-C170/HDPE-PP (d)	28.3 ± 6.8	2.4 ± 0.3	19.5	6.4	71.7
A-C170/LDPE (w)	8.2 ± 0.5	1.3 ± 0.3	6.2	0.7	91.8
A-C170/LDPE (d)	8.7 ± 1.2	1.2 ± 0.4	6.6	0.9	91.3

Overall, the distribution of the particulate matter constitution is consistent with that reported by Austroads (2022b) and Part A where it is mostly comprised by aggregates, followed by bitumen and with the least particulate matter release being attributed to microplastics.

From Table 4.5, A-C170/HDPE-PP (d) experienced the greatest mass loss during TGA followed by A-C170 and with A-C170/LDPE (w) experiencing the least mass loss. As previously discussed, the overall mass loss of the slabs following abrasion can be attributed to the morphology of the slabs' surface. The abraded surfaces of these slabs are shown in Figure 4.30. Notably, although the content of HDPE/PP and LDPE during the dry process was the same, A-C170/HDPE-PP (d) experienced significantly greater mass loss than A-C170/LDPE (d). The slabs were mixed at the same temperature of 160 ± 10 °C but the melt temperatures of the 2 polymers, LDPE and HDPE, vary with the former being typically within the range of 110 and 120 °C and the latter between 130 and 149 °C (Brasileiro et al. 2019). This difference could potentially have affected their interactions with the aggregates and the bitumen as the LDPE is more likely to have effectively melted during mixing partially adhering to the aggregates. HDPE's higher melt temperature could indicate that the polymer only softened, but did not melt during mixing and, hence, it is suspected that it did not adhere to the aggregates. As a result, HDPE/PP behaved like an aggregate in the slab and, as it is notably softer than the quarry aggregates, was abraded faster leading to an overall greater mass loss.

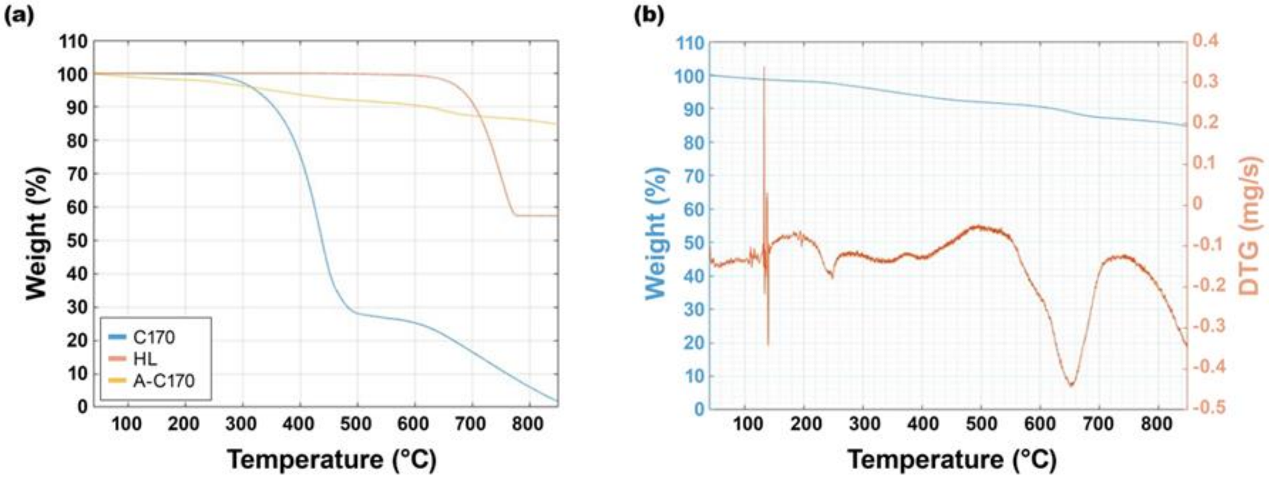
Figure 4.21 shows the TGA and DTG curves for a representative specimen of the unmodified C170 bitumen. Two degradation regions were observed, one between approximately 240 and 523 °C where the C170 loses approximately 70% of its mass and the next up to 870 °C where 29% of the mass is further lost. The onset of degradation was graphically derived at approximately 364 °C and the maximum rate of degradation for the first stage was at 430 °C, while for the second at 694 °C according to the DTG curves.

Figure 4.21: Representative TGA curve for C170



The degradation of the particulate matter for the control slab (A-C170) is presented in Figure 4.22. As the maximum degradation rate for temperatures above 500 °C, at 612 °C, does not coincide with that of HL, at 754 °C as illustrated in Figure 4.8 (b), it is assumed that all mass loss above 200 °C was due to the degradation of the bitumen.

Figure 4.22: Representative TGA curves for (a) B-C170, HL, and A-C170, and (b) representative TGA and DTG curves for A-C170



The DTG curve in Figure 4.23 (b) shows a slight, but noticeable peak between 300 and 400 °C, one between 400 and 500 °C, and another around 612 °C. All are in line with those observed in Figure 4.23 (c) for EVA and Figure 4.23 (d) for B-C170/EVA. This suggests that EVA is present in the particulate matter as previously found for A-C320/EVA. These observations are in line with the findings of Adothu et al. (2020) and Luo and Chen (2011), discussed in Section 4.1.3.

Figure 4.23: Representative TGA curves for (a) EVA, HL, B-C170, B-C170/EVA, and A-C170/EVA, and representative TGA and DTG curves for (b) A-C170/EVA, (c) EVA, and (d) B-C170/EVA with the denoted figures reflecting the average of 3 specimens

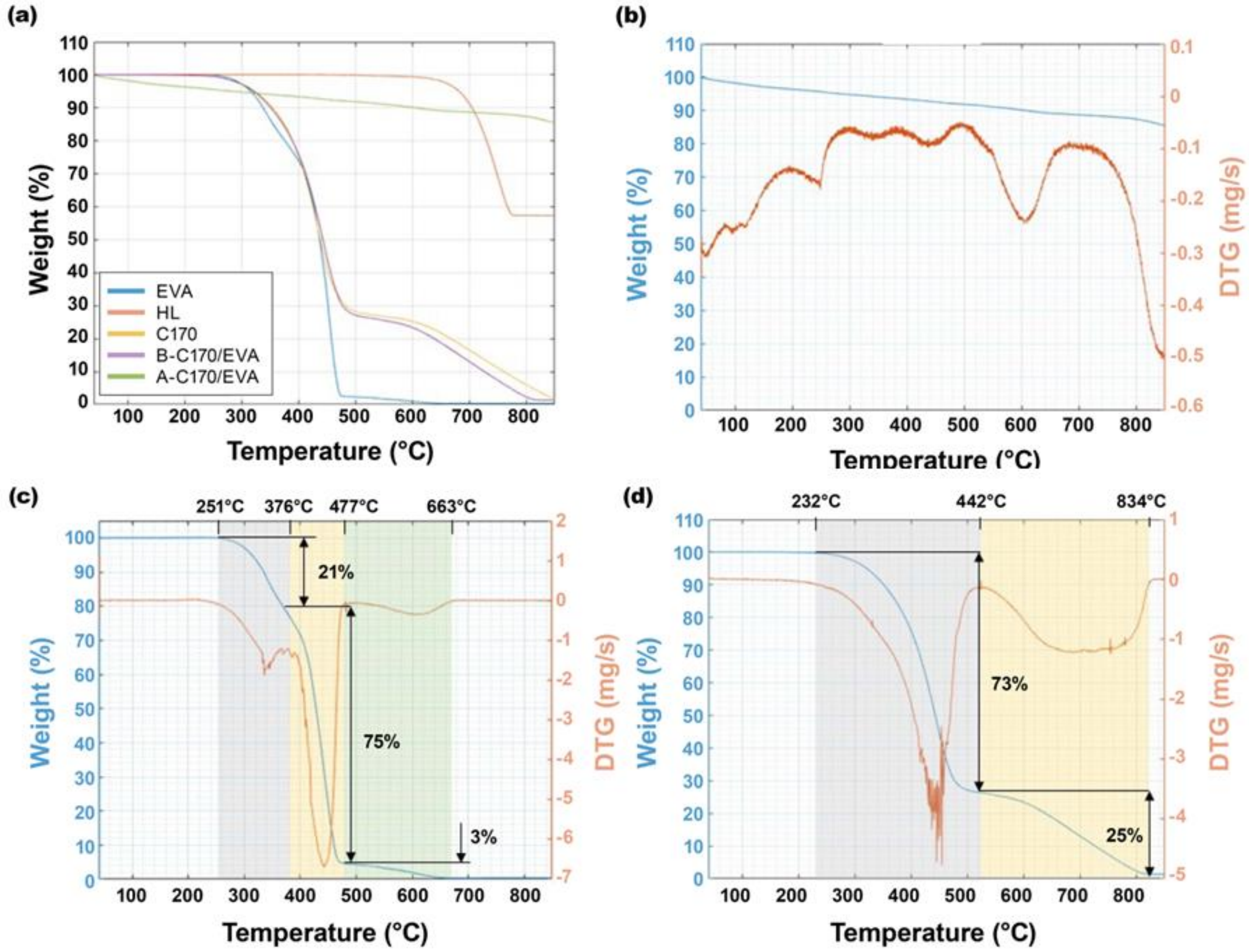
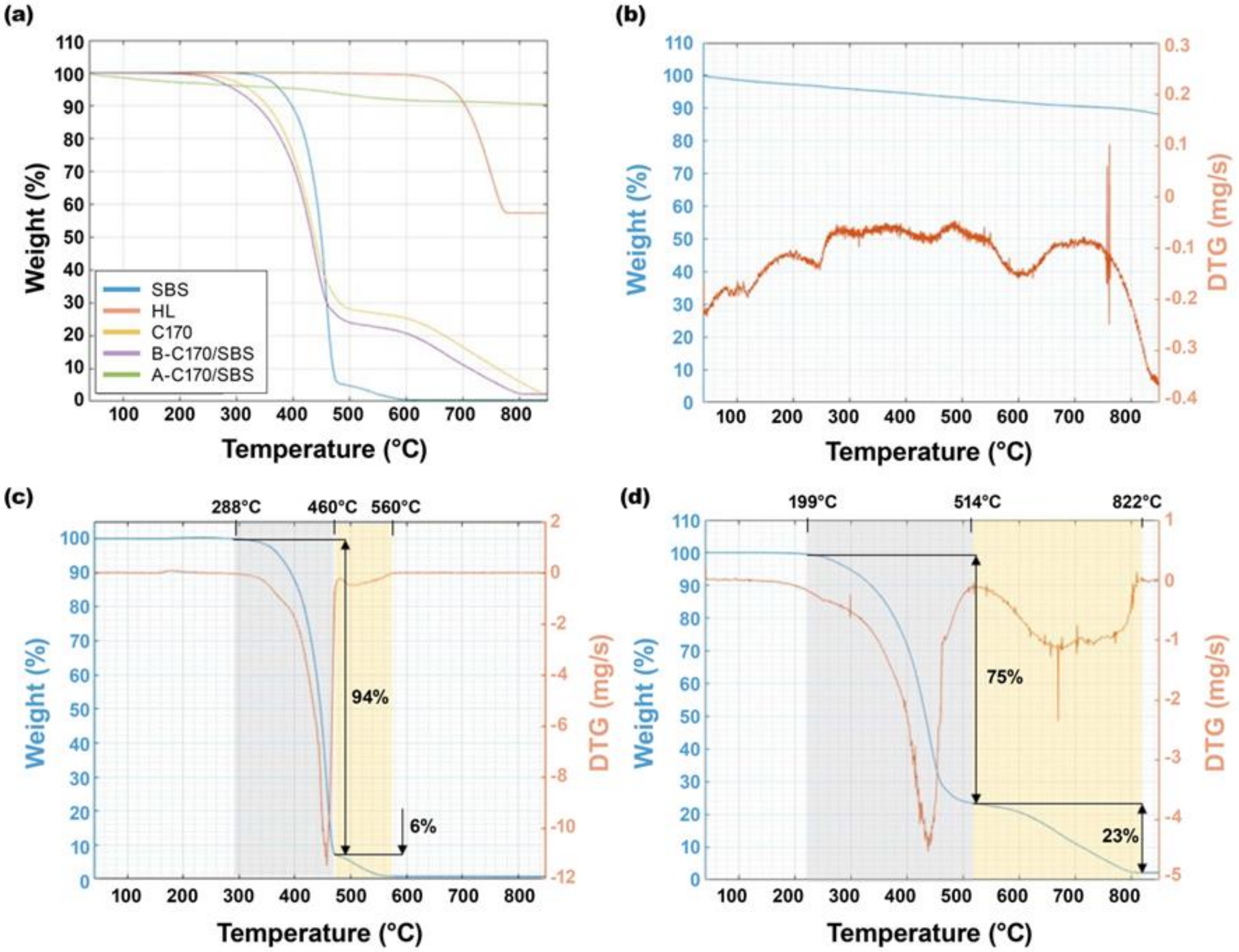


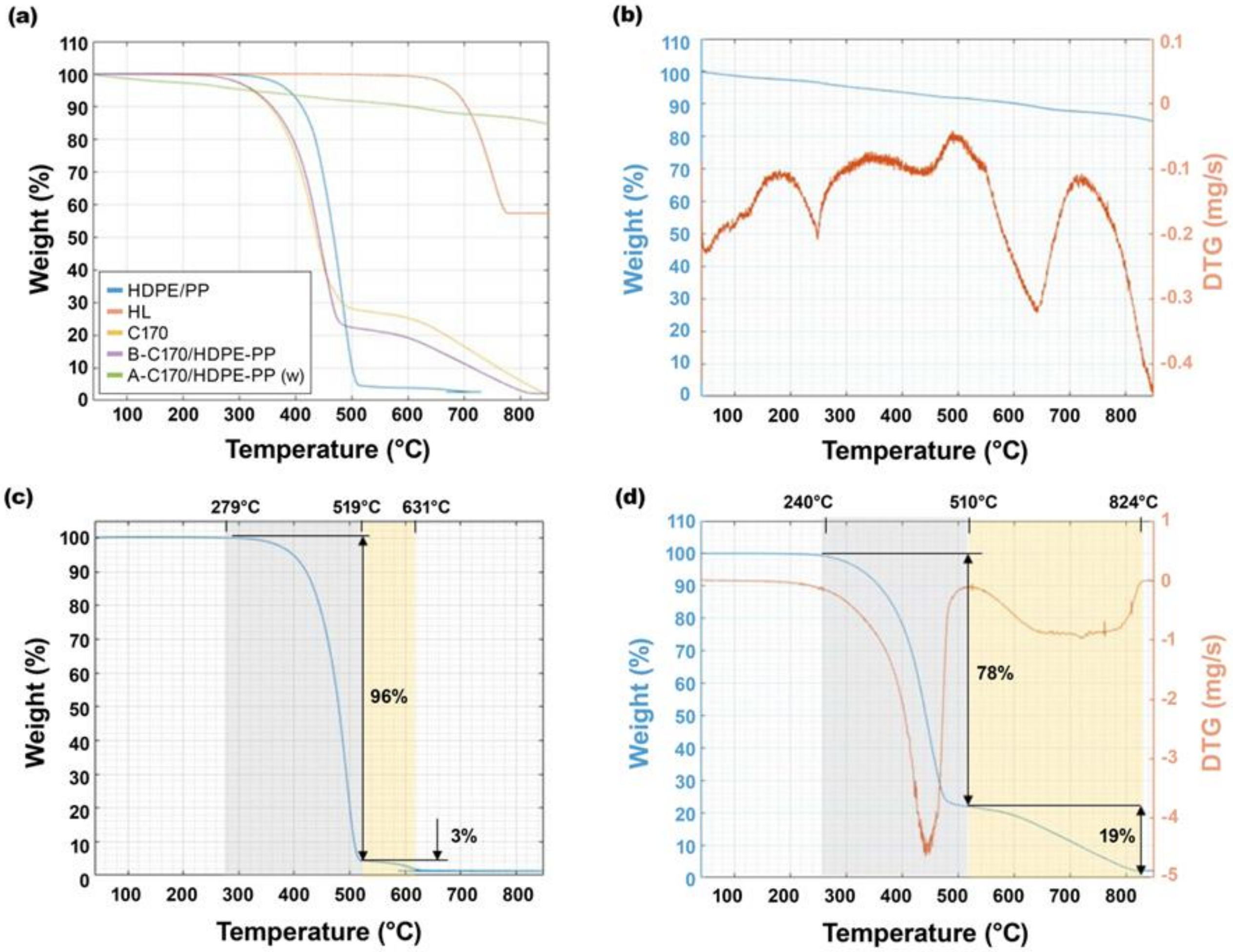
Figure 4.24 (b) shows the TGA and DTG curves for A-C170/SBS. The variable degradation regions are not distinct in the TGA curve, or for any of the specimens within the sample group analysed, but the DTG peaks for all are comparable with those in Figure 4.10 (b), also suggesting the presence of SBS in the sample. This allows for some confidence when calculating the concentration of SBS.

Figure 4.24: Representative TGA curves for (a) SBS, HL, B-C170, B-C170/SBS, and A-C170/SBS, and representative TGA and DTG curves for (b) A-C170/SBS, (c) SBS, and (d) B-C170/SBS with the denoted figures reflecting the average of 3 specimens



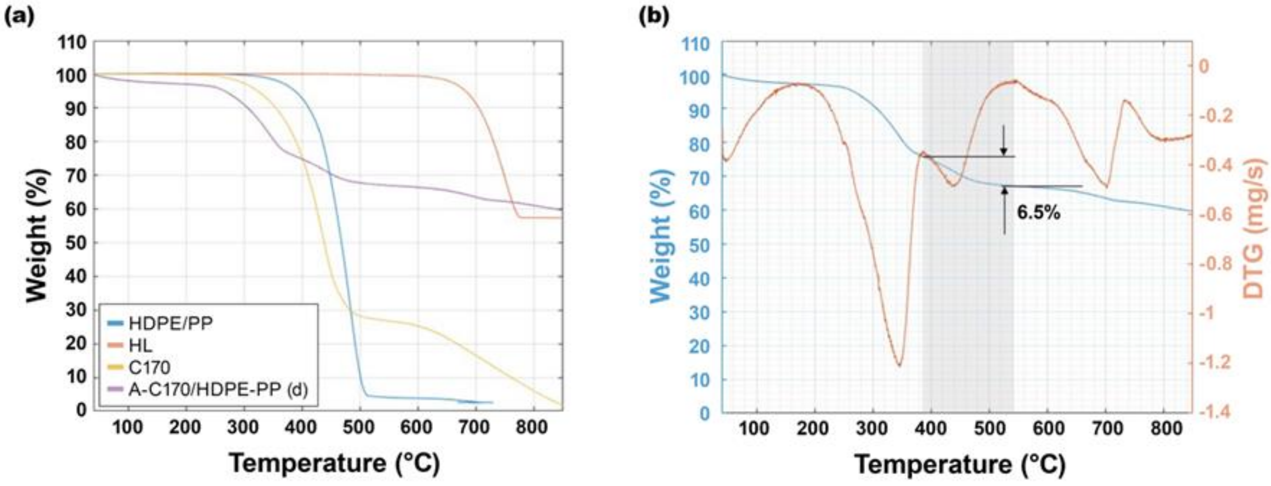
The DTG peaks for the abraded sample of Figure 4.25 (b) above 200 °C around 441 and 636 °C coincide with those of the modified binder (B-C170/HDPE-PP) in Figure 4.25 (d). The total mass loss of samples A-C170/HDPE-PP (w) is comparable to that of A-C170, A-C170/EVA, and A-C170/SBS. However, the calculated amount of microplastics released by A-C170/HDPE-PP (w) was 0.5% greater than that of A-C170/EVA and A-C170/SBS. This was because 10 wt.% HDPE/PP was added to the binder during blending, compared to the amount of EVA and SBS added at 6 and 6.5 wt.%, respectively.

Figure 4.25: Representative TGA curves for (a) HDPE-PP, HL, B-C170, B-C170/HDPE-PP, and A-C170/HDPE-PP(w), and representative TGA and DTG curves for (b) A-C170/HDPE-PP (w), (c) HDPE-PP, and (d) B-C170/HDPE-PP with the denoted figures reflecting the average of 3 specimens



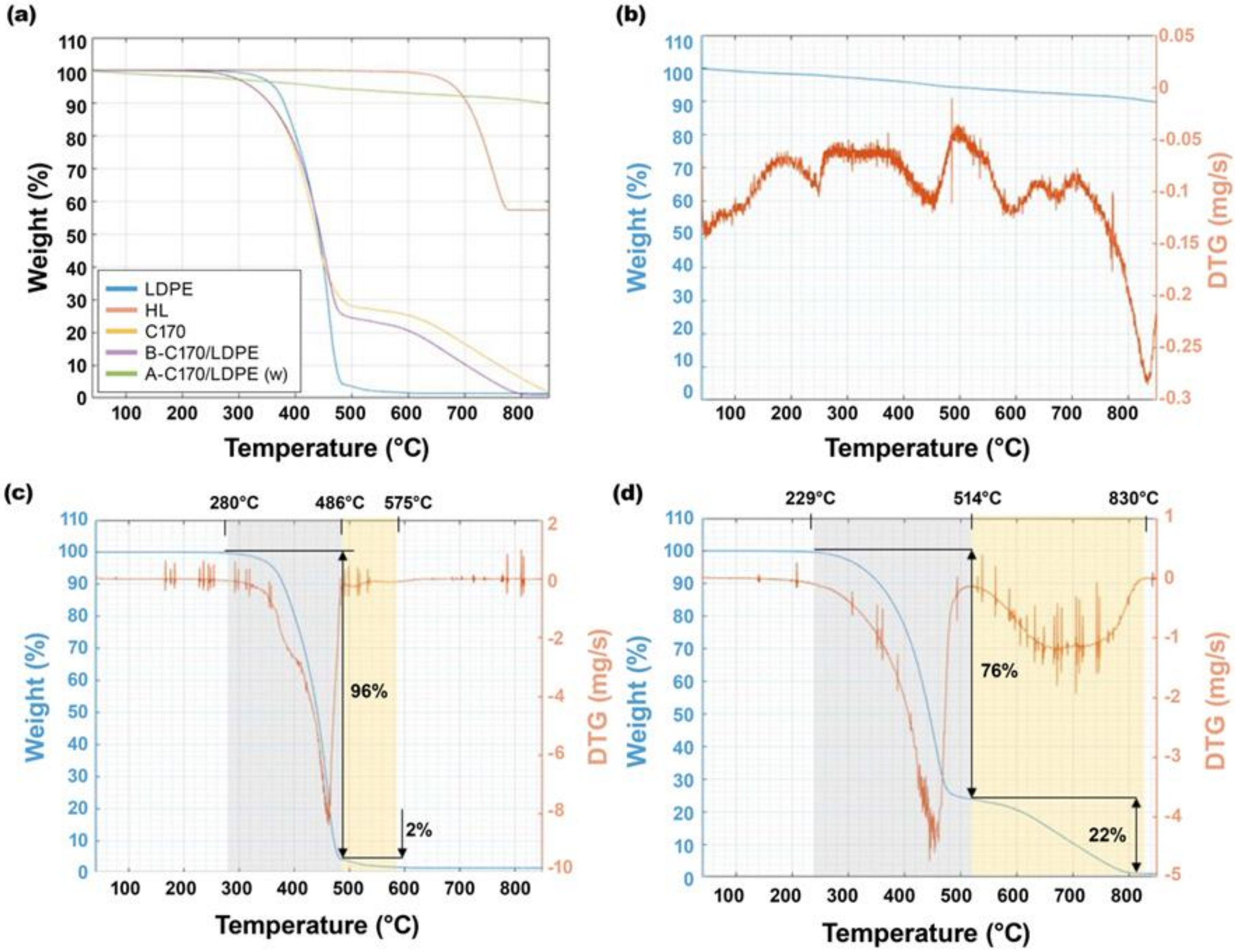
From Figure 4.26 (b), where the TGA and DTG curves for the A-C170/HDPE-PP (d) are presented, the region reflecting the degradation curve of the polymer can be distinctly identified between 380 and 525 °C. Therefore, the concentration of microplastics present in the abraded sample was directly quantified. When compared to all other samples, A-C170/HDPE-PP (d) had the greatest mass loss overall.

Figure 4.26: Representative TGA curves for (a) HDPE-PP, B-C170, HL, and A-C170/HDPE-PP (d), and (b) representative TGA and DTG curves for (b) A-C170/HDPE-PP (d) with the denoted figures reflecting the average of 3 specimens



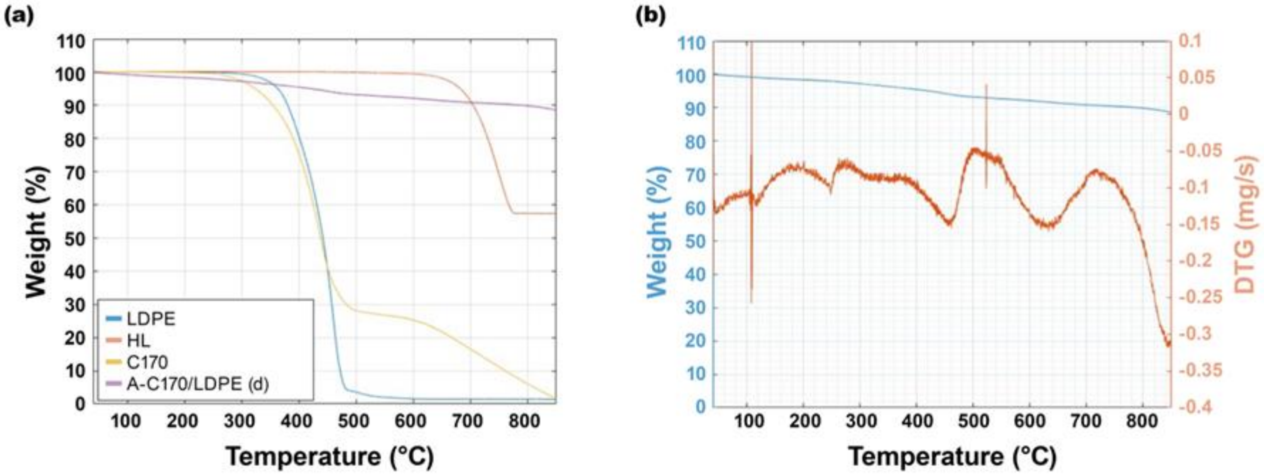
The morphology of the DTG curve between 300 and 400 °C in Figure 4.27 (b) for A-C170/LDPE (w) closely resembles that of the LDPE where a shoulder prior to the main peak is visible. This suggests the presence of LDPE in the abraded matter. Although the mass loss of sample A-C170/LDPE (w) was lower than that of A-C170/EVA and A-C170/SBS, the calculated concentration of microplastics was 0.3% greater. This was again due to the greater content of LDPE in the binder.

Figure 4.27: Representative TGA curves for (a) LDPE, HL, B-C170, B-C170/LDPE, and A-C170/LDPE(w), and representative TGA and DTG curves for (b) A-C170/LDPE(w), (c) LDPE, and (d) B-C170/LDPE with the denoted figures reflecting the average of 3 specimens



In Figure 4.28, although a distinct peak at 440 °C in the DTG curve is observed, it is not possible to confidently measure the mass loss of LDPE within the region between 278 and 499 °C. This is because C170 also loses most of its mass within that region. However, all of the LDPE is expected to have decomposed within that region meaning that mass losses beyond 499 °C can be attributed to the C170. At the second decomposition stage, C170 loses 29% of its mass. This means that the 2.2% mass loss of A-C170/LDPE (d) can be attributed to the mass loss of C170 that is approximately 1/3 of its content in the particulate matter.

Figure 4.28: Representative TGA curves for (a) B-C170, HL, and A-C170/LDPE(d), and (b) representative TGA and DTG curves for (b) A-C170/LDPE(d)



As seen in Section 4.1.3, the distribution of the constituents of the particulate matter over 1 m^2 for 60 minutes of abrasion is presented in Figure 4.29. As expected, the greatest concentration of microplastics is expected to be released when HDPE/PP is incorporated via the dry method. However, interestingly, this was followed by A-C170/LDPE (w), which according to Table 4.5 had lower content of microplastics than A-C170/HDPE-PP (w) and A-C170/LDPE (d), as measured by TGA. This is because the overall mass abraded by A-C170/LDPE (w) was comparatively greater.

Figure 4.29: Abraded matter constitution over 1 m^2 for 60 minutes of abrasion

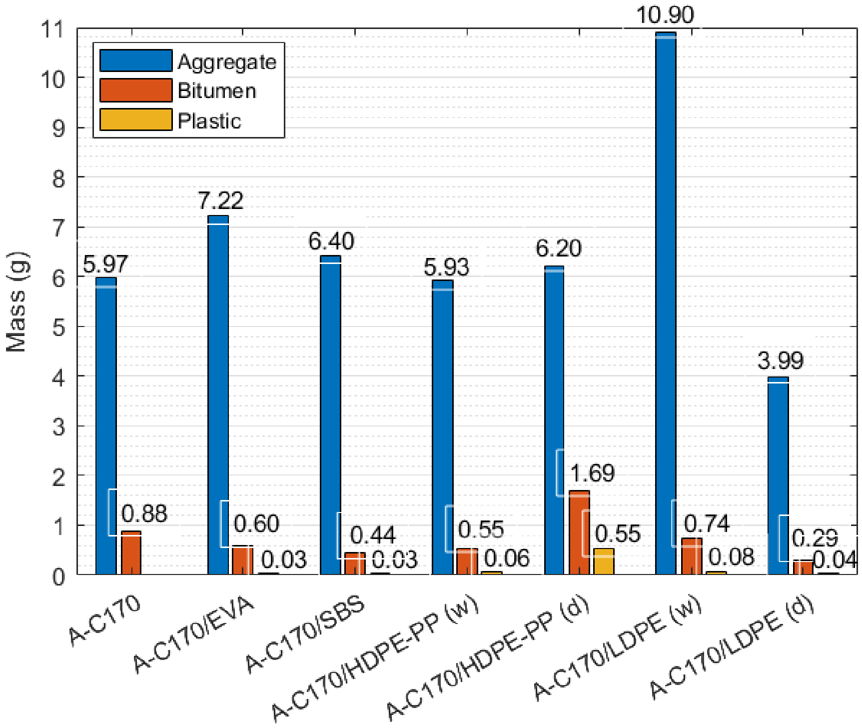
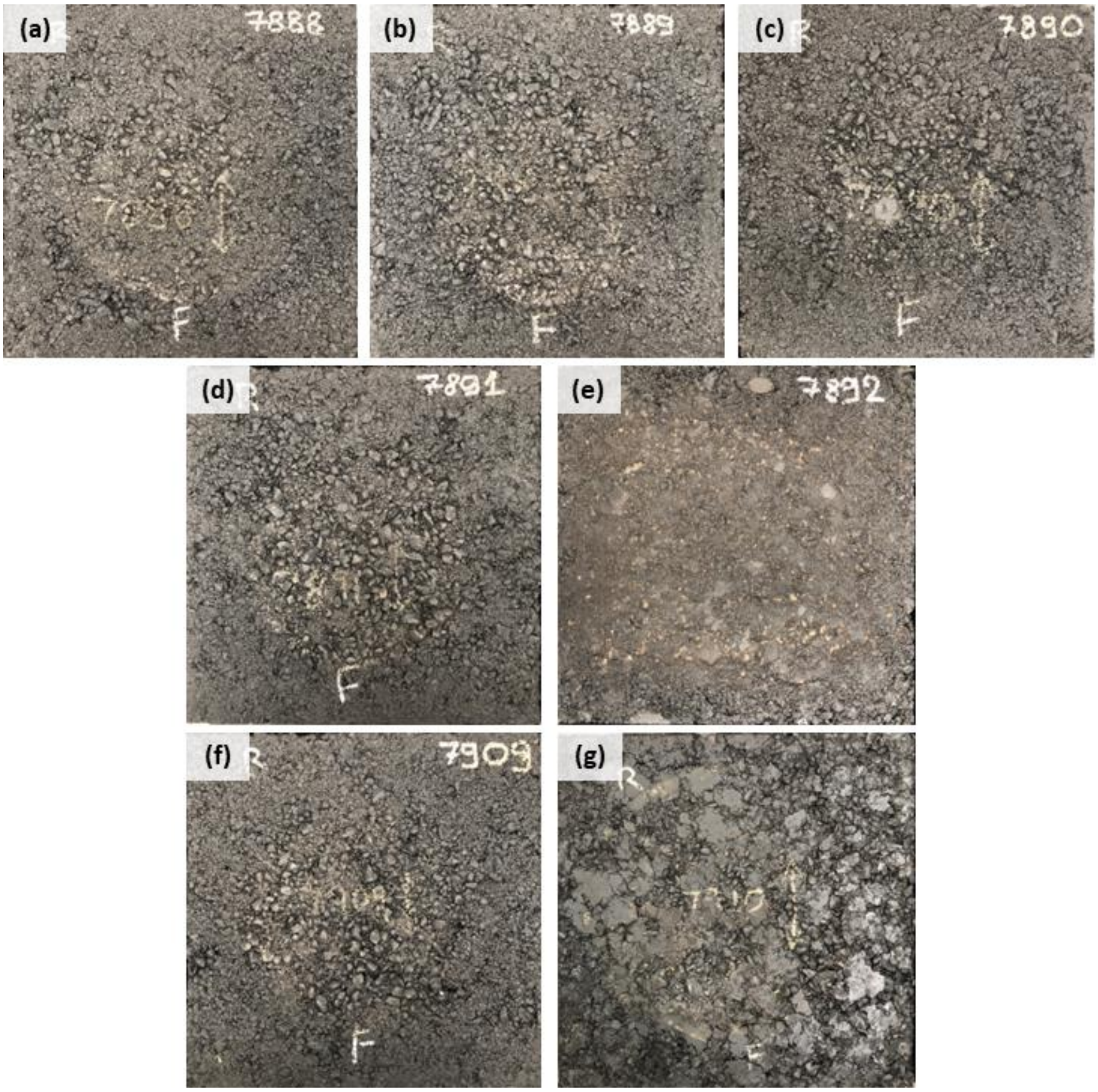


Figure 4.30 shows the surface of the slabs after 1 hour of abrasion. The morphology of the surface, in a macro scale, of most samples appears similar with comparable surface roughness. That of the dry mixes in Figure 4.30 (e) and Figure 4.30 (g), however, appears less rough and in the case of the latter, the surface appears to be primarily comprised by LDPE and C170.

Figure 4.30: Surface of slabs following 1 hour of abrasion: (a) A-C170, (b) A-C170/EVA, (c) A-C170/SBS, (d) A-C170/HDPE-PP (w), (e) A-C170/HDPE-PP (d), (f) A-C170/LDPE (w), and (g) A-C170/LDPE (d)



5 Conclusions and Recommendations

In this project, methods for the assessment of the impact of adding recycled plastics on human health and the environment were developed and assessed. Fumes and emissions were assessed using in-person, static, and absolute measurements, leachates were evaluated through GC/MS following 2 different preparation methods and following a standard method commonly used for leachates in soils, and microplastics were measured through a bitumen dissolution and density separation method and through TGA.

5.1 Fumes and Emissions

In-person and static measurements, representing exposure to fumes and emissions to the operators undertaking the binder blending and asphalt mixing tasks as well as to others operating within the area, showed that for all compounds detected, the concentrations were notably below the exposure limits set by Safe Work Australia (2022). A benchmarking method using an enclosed environment was also used, which revealed that most analytes were emitted at greater concentrations by the commonly used materials, except of formaldehyde, which was found at greater concentrations to be emitted by the sample containing LDPE.

TSPs do not have set limits for exposure; however, the detected limits were well below 5 mg/m^3, which is the upper limit for exposure recommended by the Australian Institute of Occupational Hygienists, as noted in Appendix B. The only other compound detected for which upper limits of exposure have not been defined was 2-methyl butane. The occasions where the addition of HDPE/PP and LDPE resulted in the emission of greater concentration of fumes were limited and, importantly, in all cases well below the Safe Work Australia limits. From Part B, the incorporation of recycled plastics was found to result in the increased emission of VOCs, PAHs, aldehydes, TSP, and BF in the laboratory in the cases summarised in Table 5.1.

Table 5.1: Summary of Part B fumes and emissions where the incorporation of recycled plastics resulted in increased fumes and emissions when compared to the baseline materials

Compound	Sample	Measurement	Unmodified sample	EVA sample	SBS sample	TWA
Aromatic hydrocarbons (static sampler)	A-C170/HDPE-PP (w)	0.03 mg/m^3	< LOR	< LOR	< LOR	790 mg/m^3 (total VOCs)
	A-C170/LDPE (d)	0.04 mg/m^3				
Aromatic hydrocarbons (in-person sampler)	A-C170/HDPE-PP (w)	0.03 mg/m^3	< LOR	< LOR	< LOR	
Aliphatic hydrocarbons (static sampler)	A-C170/HDPE-PP (w)	0.79 mg/m^3	0.18 mg/m^3	0.46 mg/m^3	0.35 mg/m^3	
Aliphatic hydrocarbons (in-person sampler)	A-C170/HDPE-PP (w)	0.64 mg/m^3	0.10 mg/m^3	0.47 mg/m^3	0.26 mg/m^3	
Formaldehyde (in-person sampler)	B-C170/LDPE	0.008 mg/m^3	0.007 mg/m^3	0.006 mg/m^3	0.007 mg/m^3	1.2 mg/m^3
	A-C170/HDPE-PP (d)	0.011 mg/m^3	0.008 mg/m^3	0.008 mg/m^3	0.008 mg/m^3	
Acetaldehyde (static sampler)	B-C170/LDPE	0.011 mg/m^3	0.006 mg/m^3	0.010 mg/m^3	0.009 mg/m^3	36 mg/m^3
Acetaldehyde (in-person sampler)	B-C170/LDPE	0.006 mg/m^3	0.000 mg/m^3	0.004 mg/m^3	0.005 mg/m^3	
	A-C170/HDPE-PP (d)	0.008 mg/m^3	0.006 mg/m^3	0.006 mg/m^3	0.007 mg/m^3	
	A-C170/LDPE (d)	0.008 mg/m^3				
TSP (static sampler)	A-C170/HDPE-PP (w)	0.59 mg/m^3	0.31 mg/m^3	0.20 mg/m^3	0.40 mg/m^3	5 mg/m^3 *
TSP (in-person sampler)	A-C170/HDPE-PP (d)	0.95 mg/m^3	0.28 mg/m^3	0.40 mg/m^3	0.72 mg/m^3	

* TWA limit not set by Safe Work Australia. AIOH recommended DNOS trigger value of 5 mg/m^3.

When comparing the results with those in the literature, it was found that the location and methods for assessment could significantly affect the results. Therefore, it is important that such parameters are taken into consideration when results across different investigations are compared. Investigation of the exposure to fumes and emissions during the asphalt laying process was not within the scope of this work. It is worth mentioning that Burstyn et al. (2000) proposed that there is a clear correlation between the application method (mastic paving ≥ repaving > hot asphalt, surface dressing > cold applications) and bitumen exposure levels. A link between temperature and emission levels also exists, where an increase in emissions is observed with an increase in temperature (Burstyn et al. 2000). This is in line with absolute laboratory investigations carried out by Austroads (Austroads 2021b; Austroads 2022a; Austroads 2022b).

5.1.1 Recommendations

The methods for assessment for the in-person and static measurements, as described in Section 3.1.3 and Appendix B, were found to be suitable for the evaluation of the impact that recycled plastics in bitumen may have on the health of the laboratory operators. As the aim was to assess the impacts on the WH&S of the laboratory operators undertaking the tasks (binder blending and asphalt mixing) as well as those operating within a near proximity of the area, it is recommended that the static samplers are placed as depicted in Figure 3.4. The low quantities detected during the monitoring of fumes and emissions by the static samplers demonstrate the efficiency of the safety measures already in place.

Laboratory operators are currently required to wear safety boots, safety glasses or face shields (during binder blending), lab coats, heat resistant gloves and, as in any laboratory activities, long pants, and long-sleeve shirts. As the results from the measurements, presented in Sections 3.1.4 and 3.2.3, between the recycled plastic-containing binders and the baseline binders (bitumen and PMBs) were comparable, it is recommended that no additional or different PPE is required during the binder blending and asphalt mixing activities. It is, however, important that current measures are followed.

Should the point of asphalt laying be of interest, it is expected that following the same methodology using the in-person samplers for the collection of compounds would also be appropriate. NACOE proposed a method for the monitoring of fumes and emissions released to the environment (Denneman et al. 2015) and perceived by the field workers at the point of laying (Grobler 2020; Grobler et al. 2017). A method for in-person fumes and emissions monitoring at the point of laying was also proposed by WARRIP for hot mix asphalt with crumb rubber (van Aswegen & Latter 2019).

Benchmarking using an enclosed test chamber can also be used to provide a direct comparison between binders containing conventional materials and those containing plastic additives. Although only one specimen per sample was analysed, it is proposed that multiple results are obtained for more accurate comparison. In addition, care needs to be taken to maintain temperature control during the process. It is also noted that the binders that can be analysed via this method are pre-blended and, therefore, fumes emitted during the initial contact between the bitumen and additive are not measured. Regardless, with these limitations in mind, such benchmarking may be used to advise whether further investigations using in-person and static samplers are required.

5.2 Leachates

The investigation of leachates from bituminous binders and asphalt is relatively underdeveloped. Although such investigations are common practice in soil, they are not in road construction. The methods developed for the assessment of leachates from the binders were found to be inconclusive. None of the analytes of interest were detected (PAHs, bisphenol-A (BPA), phthalates, styrene, and hydrocarbons). It was, therefore, thought it was possible that the binders did not leach under the selected exposure procedures as described in Sections 4.1.2 and 4.2.2 and/or that the GC/MS method used was not appropriately calibrated. GC/MS calibration to specific analytes of interest is a rather resource and time intensive process when non-standard methods and materials are used but should be considered in future. The dry method mixes were not assessed via this method.

In Section 4.2.2, following SQP advice (Appendix C) the standard method used for soils was also investigated in loose asphalt mix. The method was found to detect certain analytes, including metals. Naphthalene was detected for A-C170 and A-C170/EVA, which was below the ground-water investigation limits. Aluminium, zinc, and nickel, however, were detected above ground-water investigation limits. It is noted though that these might be due to ore bodies within the proximity of mining or quarrying activities. As such, it may be argued that their presence is due to the aggregates in the loose mix asphalt which were crushed prior to analysis. This was further investigated through the analysis of uncrushed loose mix asphalt. The PAH results were consistent with those of the crushed loose mix asphalt, which is expected due to the presence of naphthalene in bitumen. The measurements of heavy metals, however, still revealed the presence of nickel and aluminium. Although nickel may also be found in bitumen, the presence of aluminium is not expected in bituminous binders. Therefore, it is suspected that during analysis water may still have penetrated through to the aggregates affecting the results. It was not possible to confidently define the source of the aluminium. To do so, further analysis of the materials independently is required. However, it appears that the samples containing plastics do not contain notably greater concentrations of aluminium when compared to the baseline materials.

5.2.1 Recommendations

As the results on the leachability not only of the recycled plastics-containing samples, but also the baseline materials, was found to be inconclusive, it is recommended that efforts to understand these effects are continued.

From the findings, it may be specified that investigating leachates unaffected by the presence of aggregates is necessary. This may be achieved following a leaching method such as that assessed in Section 4.2.2 for the bituminous binders. Care needs to be taken to appropriately calibrate the GC/MS prior to analysis. Another possible pathway would be to that of field trials, such as those possible in an accelerated loading facility, where the surrounding soil is assessed for leachates following AS 4439.2 and AS 4439.3.

The effect of ageing (thermo-oxidative and UV) warrants investigation. This is because chain scission might be found to increase the susceptibility of the materials to leaching.

5.3 Microplastics

The release of microplastics through bitumen dissolution and density separation was found to be challenging to quantify. This was due to assumptions that had to be made during the process, the solubility of SBS in low odour kerosene, the persistent floatation of small aggregates on the surface of glycerine, and the absorption of glycerine by the selected filters. In addition, the process was found to be rather time consuming.

On the other hand, TGA was found to be effective and efficient in quantifying the released microplastics in the abraded matter with testing for each specimen requiring 5 minutes of preparation and approximately 2 hours of testing. The microplastics released were overall found to be comparable through this method across all samples investigated. The only exception was the amount of microplastics found in the abraded matter of A-C320/HDPE-PP (d). This was due to the presence of unmolten HDPE/PP particles in the asphalt which were thought to abrade more rapidly than the aggregates. Another factor that was found to affect the quantity of binder (bitumen and additive) released following abrasion was the surface morphology of the slabs as well as the consistency in the coating of the aggregates by the binder. To quantify the concentration of microplastics in the portion of abraded matter that degraded during TGA, an even distribution of the additive within the binder was assumed. It was thought that such an assumption was reasonable to make, given that the binders used for application in Australia have a requirement to not segregate. The assessment of the type of plastic and morphology of the released microplastic through this method was not possible.

5.3.1 Recommendations

The slabs studied were thermo-oxidatively aged following AASHTO R30-02 prior to being abraded. Thermo-oxidative or UV ageing is recommended as such ageing often results in chain scission of the polymer chains leading to embrittlement and, therefore, to potentially asphalt surfaces more susceptible to abrasion.

It is, therefore, recommended that for the quantification of microplastics, TGA is used. If the equipment is not available in the asphalt laboratory where the work is to be undertaken, universities and analytical laboratories across WA and Qld have that capacity. Given the small specimen size, it is advisable that multiple specimens per sample are analysed.

Should the investigation of the morphology or the type of the released microplastics be of interest, the bitumen dissolution and density separation method would be suitable. This method allows for the visual assessment of the microplastics collected from the surface of the glycerine (or other appropriate solvent). In addition, although not investigated, it is reasonable to expect that assessing the type of the microplastics collected through an IR method, such as FTIR or LDIR could be achieved. Similarly, if an optical microscope and FTIR equipment are not available in the asphalt laboratory conducting the analysis, universities and analytical laboratories across WA and Qld have that capacity.

5.4 Future Research

In future, it is recommended that the proposed protocols summarised in Appendix G are fully assessed. This would include:

- the evaluation of the effect of UV ageing in the leachability of potentially harmful-to-the-environment compounds and microplastics release
- a field trial while monitoring the release of fumes and emissions at the point of asphalt laying.

To fully assess the capacity of recycled plastics to replace EVA and/or SBS, the field trial should be continuously evaluated in its properties with sampling taking place at intervals over a specified period of time.

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Appendix A Initial Suitably Qualified Person Review

Reclaimed Plastics in Road Infrastructure: Technical Review

Prepared for: Australian Road Research Board (ARRB), Main Roads Western Australia and Queensland Department of Transport and Main Roads

27 June 2023

EnRiskS

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Limitations

Environmental Risk Sciences has prepared this report for the use of the Australian Road Research Board (ARRB), Main Roads Western Australia (MRWA) and the Queensland Department of Transport and Main Roads (TMR) in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report.

It is prepared in accordance with the scope of work and for the purpose outlined in the **Section 1** of this report.

The methodology adopted and sources of information used are outlined in this report. Environmental Risk Sciences has made no independent verification of this information beyond the agreed scope of works and assumes no responsibility for any inaccuracies or omissions. No indications were found that information provided for use in this assessment was false.

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Appendices:

Executive summary

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by the Australian Road Research Board (ARRB), on behalf of the Queensland Department of Transport and Main Roads (TMR) and Main Roads Western Australia (MRWA) to undertake a technical review and provide advice in relation to the potential use of reclaimed plastic in road infrastructure.

The use of reclaimed plastics in all road construction, may involve the following applications:

- asphalt and sprayed seals
- geosynthetics (geofabrics and geogrids for earthworks or asphalt and seal surfacings)
- railway sleepers
- bike paths and footpaths
- noise and retaining walls
- pipes, conduits and pits
- fencing, barriers, bollards, wheel stops and kerbs
- signage and other roadside furniture
- equipment (such as traffic cones)
- bins, tables, seats, artwork, garden edging, tree stakes, and architectural screens, and
- as structural and non-structural lumber – including for formwork, decking, etc.

A specific area of interest is the use of plastics in asphalt and sprayed seals, however, general advice is also required for other proposed uses. Hence the key focus of this report relates to the use of plastics in asphalt and sprayed seals.

The proposed use of reclaimed plastic in road infrastructure is part of a broader framework being considered in Queensland and Western Australia in relation to the use of recycled materials.

The objectives of the review undertaken and presented in this report are to determine if the proposed use of reclaimed plastics in asphalt and sprayed seals:

- changes the characteristics of the asphalt and sprayed seal products
- has the potential to change workplace exposures,
- has the potential to change exposures within the community or environment
- if the changes in exposure have the potential to result in elevated risks to human health or the environment
- if any additional management measures may be required for the use of products that include reclaimed plastics.

This review has not provided an assessment of the engineering requirements or specifications relevant to the use of reclaimed plastics as proposed. The focus of this review relates to the potential for harm to human health and the environment.

When assessing any modified material that may be used for road infrastructure, the first stage should be benchmarking of the characteristics of the material against the traditional materials. Insufficient data is available on the traditional and plastic modified asphalt and spayed seals to enable benchmarking to be undertaken in this review. Hence the review has focused on the identification of key risk issues and data gaps relevant to evaluating human health and environmental risks. When these data gaps are addressed, benchmarking should be used as the first stage in a detailed assessment.

The risks related to the use of recycled plastics are highest where the recycled plastic is used in a dry or hybrid process as the plastic would remain unchanged within the aggregate and chemicals present as additives (and potentially contamination) to the plastic materials can leach from the materials, and the ageing of road materials may result in the generation of increased levels of microplastics.

Where recycled plastic is used in a wet process it is expected to be chemically bound within the bitumen and would not be available for leaching or the generation of microplastics. The potential for the generation of microplastics over time (with wear and tear) is unknown and may be an issue of concern for the long-term use of these materials.

Insufficient data and information are available on the characteristics of asphalt/bitumen modified with recycled plastic to make conclusions in relation to environmental impacts. There is some information that indicates that impacts (particularly in relation to leachate) are higher where chlorinated plastics may be used. While data is lacking, to minimise potential risks to workers and the community it is recommended that recycled chlorinated plastics should not be used in any road infrastructure.

A number of data gaps have been identified that need to be addressed through data collection to inform the suitability, or otherwise, of recycled plastic in asphalt and bitumen.

The data gaps identified are summarised below:

- Workplace exposures
    - Lack of data relating to bitumen/asphalt fume in air for Australian environments where asphalt is utilised. The variability in concentrations needs to be understood for existing workplace environments.
    - Data on the characteristics, as air concentrations that workers would be exposed to, of fume derived from standard asphalt/bitumen, as well as plastic modified asphalt/bitumen. This would include asphalt/bitumen fume, as well as TRH, VOCs and semi-volatile organic compounds (SVOCs) in fume. Odours relating to plastic modified asphalt/bitumen, with comparison against standard fume, would also be required.
    - Information on existing PPE required to manage bitumen fumes in the workplace, and any additional PPE that may be required to address the proposed reduction in the workplace exposure standard. This is important to consider when evaluating workplace exposures to materials that include recycled plastic, where fume and vapour emissions are different to traditional materials.
- Leachate from road materials
    - Limited leach test data is available for asphalt and bitumen materials. More specifically there is limited publicly available data for leaching from asphalt pavement and road surfaces with bitumen sprayed seals in Australia. It is expected that the leachable levels would be variable, and likely to different from materials internationally (due to the source of base products such as bitumen). Hence one of the key data gaps is the variability in leaching from standard asphalt and road surfaces (bitumen sprayed seals). This data may already be available with various organisations. If it is available, the data needs to be obtained and compiled. If not

  - available, sufficient number of samples need to be analysed for leaching (neutral) to determine the variability in leaching from these materials.
  - Leach testing would also need to be undertaken on the plastic modified materials as solids and also as crushed reclaimed asphalt (at the end of the asphalt cycle prior to recycling and reuse). This would need to evaluate leaching (neutral) from sufficient numbers of samples to determine variability. The testing should also consider weathered materials.
  - All leach tests (standard asphalt and bitumen as well as plastic modified materials) need to be analysed for the same contaminants. This would include metals, PAHs, hydrocarbons (as total recoverable hydrocarbons [TRH] and individual hydrocarbons), BPA, phthalates and styrene as a minimum.
- Generation of microplastics
  - The review by VTI (Andersson-Sköld et al. 2020) identified that there are significant knowledge gaps regarding: the amounts of microplastic particles emitted as a result of tyre, road, and road marking wear; the sizes of the generated particles; how they spread and potentially change in the environment; at what concentrations they are present in different environments; the extent of human and ecological exposure to these particles; and the environmental and human health hazards posed by microplastics from road traffic.
  - There are also significant knowledge gaps regarding different methods that can be used to limit the generation of microplastics from road traffic, and their respective effectiveness (Andersson-Sköld et al. 2020).
  - In Australia, there is no publicly available data on the presence and characteristics of microplastics from roadways. To be able to determine if there are any differences in microplastics from plastic modified asphalt or bitumen products, studies would need to be undertaken on standard materials, and the plastic modified materials. These studies would need to be undertaken using the same methodology to ensure that the data are comparable, and that differences in microplastic generation can be evaluated (if present). The studies would need to review the composition, size and shape if the microplastics from fresh and weathered materials, as well as crushed weathered materials as would occur when asphalt is removed and recycled.
  - Standardised and reliable/repeatable tests for the generation of microplastics from various materials need to be developed and applied for traditional and plastic modified materials.

Section 1. Introduction

1.1 Background

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by the Australian Road Research Board (ARRB), on behalf of the Queensland Department of Transport and Main Roads (TMR) and Main Roads Western Australia (MRWA) to undertake a technical review and provide advice in relation to the potential use of reclaimed plastic in road infrastructure.

The use of reclaimed plastics in all road construction, may involve the following applications:

- asphalt and sprayed seals
- geosynthetics (geofabrics and geogrids for earthworks or asphalt and seal surfacings)
- railway sleepers
- bike paths and footpaths
- noise and retaining walls
- pipes, conduits and pits
- fencing, barriers, bollards, wheel stops and kerbs
- signage and other roadside furniture
- equipment (such as traffic cones)
- bins, tables, seats, artwork, garden edging, tree stakes, and architectural screens, and
- as structural and non-structural lumber – including for formwork, decking, etc.

A specific area of interest is the use of plastics in asphalt and sprayed seals, however, general advice is also required for other proposed uses. Hence the key focus of this report relates to the use of plastics in asphalt and sprayed seals.

The proposed use of reclaimed plastic in road infrastructure is part of a broader framework being considered in Queensland and Western Australia in relation to the use of recycled materials.

It is noted that the use of recycled/reclaimed plastics and toners are currently approved for use in asphalt in some jurisdictions such as NSW.

The use of reclaimed plastics in asphalt and sprayed seals, and other road related infrastructure, requires review in relation to potential exposures to workers, community and the environment throughout its use. Asphalt and sprayed seals are utilised throughout the industry, with existing exposures to workers, community and the environment occurring and managed. The focus of this review relates to how the inclusion of reclaimed plastics in these products may change the nature of the materials and/or the exposures that may occur for workers, community or the environment. The outcomes of the review relating to asphalt and sprayed seals can also be applied to other potential uses of reclaimed plastics. Where such exposures may differ from existing, an assessment of the significance of these exposures is relevant.

This review will require the identification of key contaminants and exposure scenarios (workplace, community and environmental) associated with asphalt and sprayed seals and whether the addition of these materials causes differences to the nature of the materials.

1.2 Objectives and scope of works

The objectives of the review undertaken and presented in this report are to determine if the proposed use of reclaimed plastics in asphalt and sprayed seals:

- changes the characteristics of the asphalt and sprayed seal products
- has the potential to change workplace exposures,
- has the potential to change exposures within the community or environment
- if the changes in exposure have the potential to result in elevated risks to human health or the environment
- if any additional management measures may be required for the use of products that include reclaimed plastics.

This review has not provided an assessment of the engineering requirements or specifications relevant to the use of reclaimed plastics as proposed. The focus of this review relates to the potential for harm to human health and the environment.

Additional data is proposed to be collected to address some known data gaps in the available information, and a technical specification is expected to be developed (by others) for the use of these materials. This report has not considered these aspects.

1.3 Methodology

This review has been undertaken in accordance with the following legislation and guidance (and associated references as relevant):

- Environmental Protection Act 1994 and Environmental Protection Regulation 2019
- Waste Reduction and Recycling Act 2011
- The Waste Avoidance and Resource Recovery Act 2007, and Regulations 2008 (WA)
- National Environmental Protection Measure (NEPM) (NEPC 1999 amended 2013b, 1999 amended 2013a, 1999 amended 2013d, 1999 amended 2013c)
- enHealth, 2012. Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012)
- Queensland – Waste Reduction and Recycling Act 2011 and Waste Reduction and Recycling Regulation 2011
- Queensland Recycled Materials Environmental Assessment framework, Draft for Consultation (2015)
- Western Australia - Waste Avoidance and Resource Recovery Act 2007 and Waste Avoidance and resource Recovery Regulation 2008
- Recycled Materials in Main Roads, Reference Guide. Mainroads Western Australia, January 2021
- Roads to Reuse, Product Specification – recycled road based and recycled drainage rock, Government of Western Australia (June 2020)
- Natspec, Use of recycled materials for roadworks in local government (April 2019).

1.4 Qualification of author/SQP

This report has been prepared by Dr Jackie Wright, Director of enRiskS. **Appendix A** presents a curriculum vitae for Dr Jackie Wright which demonstrates that she meets the requirements of a Suitably Qualified Professional (SQP) for the assessment of harm to human health and the environment. **Appendix D** presents the required statutory declarations relevant to this assessment.

Section 2. Use of recycled plastics in road construction

The use of reclaimed or recycled plastics in asphalt and bitumen seals is currently a hot topic in Australia as federal and state governments develop policies for potential recycling of waste plastics within Australia, rather than exporting for processing offshore. These products may have also been used in other jurisdictions in Australia, however specific regulatory approval is not available. A number of councils throughout Australia have indicated that they are participating in trials and pilot road construction projects that include the use of recycled products such as plastics (NATSPEC 2019). Plastics make up only a small proportion of recycled materials currently used in road construction in Australia (NATSPEC 2019).

Various local and international companies are involved in Australian field trials that incorporate waste plastic into asphalt mixture. Each company applies different approaches to incorporating waste plastic in asphalt. This includes the use of waste plastic, predominantly low-density polyethylene (LDPE), with some high-density polyethylene (HDPE), polypropylene (PP) and small amount of polyethylene terephthalate (PET), and various polymers (including modified toner polymer or MTP) in asphalt and spray seal pavements at varying percentages.

There are no resource recovery measures (or similar) are available for the use of recycled materials in road infrastructure in Queensland or Western Australia.

The NSW EPA has issued a Resource Recovery Order under Part 9, Clause 93 of the Protection of the Environment Operations (Waste) regulation 2014 – The Downer bituminous pavement order 2020. The product website indicates that the product was subject to testing, including the potential leaching of chemicals and the release of microplastics. The test results referenced on the product website are not publicly available and have not been reviewed in this assessment.

The NSW EPA has also issued a Resource Recovery Order under Part 9, Clause 93 of the Protection of the Environment Operations (Waste) regulation 2014 – The recovered tyres order 2014. This includes the use of recovered tyres for applications that include road making. The order includes compliance requirements in relation to levels of metals, electrical conductivity and present of other materials. The Order requires the product to be tested prior to being supplied. While not specific to the use of reclaimed plastics, the Order provides some context as to the requirements for testing that may need to be considered for other recycled materials that may be used in road construction.

Internationally, Canada (Vancouver) incorporated plastic crate waste as a warm asphalt wax additive in 2012 and Rotterdam (The Netherlands) had a plan in 2015 to produce recycled plastic segments for road construction (White, G. & Reid, G. 2018). In 2018 a cycleway 30 m in length constructed of recycled plastic (bottles, cups and packaging) was opened in The Netherlands (Austroads 2019a). India has more than 33,000 km of plastic road, constructed from shredded plastic.

In 2015 Scotland MacRebur, a Scottish company, developed a recycled plastic extender/modifier known as MR6. When in pellet form MR6 can be incorporated into the asphalt production plant. Other products known as MR8 and MR10 were also produced. These recycled plastic waste products have been incorporated into stone mastic and dense graded asphalt mixtures for surfacing and resurfacing works for truck parking depots, roads and service stations in the UK. The runway and taxiways at Carlisle Airport (England) were recently resurfaced and waste plastic modified asphalt was paved and performed consistently with the conventional, unmodified asphalt (White, G. & Reid, G. 2018).

These products (MR6, MR8 and MR10) have also been used in trial in Australia (Austroads 2019a), specifically for Brisbane City Council.

Other products noted in the literature include PolyPave (which contains recycled glass, asphalt and HDPE, used in a trial in the City of Yarra in Victoria) and PlastiPhalt (which includes plastic from used oil containers with trials conducted in the City of Port Philip in Victoria and in Christchurch New Zealand) (Austroads 2019a).

While information is available about the uses of these products, no data is available for these products as used in Australia or in other countries that assists in understanding the characteristics of the products and potential environmental impacts.

Other road infrastructure

In relation to other road infrastructure, recycled plastic is being used in road aesthetics such as signage, roadside furniture, tree stakes, boardwalks, and decking. Replas is one of the recycled plastic product companies, which states that it uses waste soft plastic (packaging plastic) provided by the REDcycle scheme to manufacture recycled products REPLAS (2020).

Other applications may include the use of recycled plastics in noise walls, as alternatives to timber, concrete, and other materials. Viscount Rotational Mouldings (VRM), which is a subsidiary of the PACT Group, produces noise walls made from recycled plastic.

Section 3. Key risk issues relevant to evaluating asphalt and seals with recycled materials

3.1 Introduction

This section provides a review of the key issues related to the assessment of potential exposures and risks related to road materials where recycled plastic may be included. To undertake this review it is important to understand the chemical and physical properties of the asphalt and sprayed seals as well as the plastic materials that may be used in asphalt or sprayed seals. A more detailed review of the nature of plastics that may be used in road infrastructure is provided within the report “Recycled Plastics in Road Infrastructure” (Draft 2021), ARRB Project No: 015611. Information from the ARRB report has been incorporated into the following discussion where relevant.

Information on the nature of the existing road materials and recycled plastics is then used to identify the key risk issues that need to be evaluated and considered in relation to human health and the environment, where recycled plastic asphalt or sprayed seals are used.

3.2 Characteristics of the materials evaluated

3.2.1 Bitumen

Bitumen can be categorised into two parts. The light oily phase, which is called maltenes, and the heavy phase, asphaltenes. When looking to modify the physical properties of bitumen, there are several common polymers that are used in the industry. SBS, SBR, and EVA are the most common examples, and they all work on the basis of being mostly soluble with the maltene phase, and creating a crosslinked network that introduces physical changes to the properties of the bitumen that include resistance to deformation, fatigue cracking and ageing; impact resistance and elasticity. The use of polymer modified binders (PMBs) in asphalt and sprayed seal surfacing is widely used across the trunk road network. The use of high-performance binders has become increasingly necessary due to the ever-increasing number of large heavy vehicles using the road network. The use of these binders also increases the time between maintenance interventions, as well as providing better performance.

Most research into the use of recycled plastic in asphalt to date has compared the performance benefits to unmodified binders.

3.2.2 Asphalt materials and seals

Pavement surfaces around the world have a long history of using bitumen as a binder in asphalt mixtures (Shell 2015). Bitumen itself is a by-product of crude oil refining for the production of petroleum gas, petroleum fuels, diesel fuel and lubricating oils. The residue from the second distillation of crude oil includes bitumen, that is then separated and processed for sale in the road, airport and port pavement construction industry as well as other industries (White, G. & Reid, G. 2018)

Traditionally, asphalt production used unmodified bitumen, usually graded according to either its viscosity or resistance to load penetration at certain temperatures. However, as the required engineering properties of asphalt mixtures increased over time, polymers, acids and other additives were incorporated to increase the resistance of asphalt mixtures to high temperature deformation, low temperature cracking and moisture damage (White, G. & Reid, G. 2018).

The primary material recycled into asphalt mixtures is recycled asphalt. Reclaimed Asphalt Pavement (RAP) is commonly stockpiled, crushed, tested and recycled back into new asphalt at the production plant (Austroads 2015). Typically, 10-20% of RAP is incorporated, with higher RAP percentages also considered when the RAP is available in higher quantities (Pires et al. 2017).

In more recent times, other recycled materials have been incorporated into asphalt mixtures. This includes toner materials, crushed concrete, crushed glass industrial slags, ash and fly ash and crumb rubber (Austroads 2019a). This review relates to the use of plastics.

Sprayed seals comprise a bituminous binder that acts as a waterproofing layer that prevents water entering the underlying road structure. The seals are also used to replenish the binder that is lost through oxidation and weathering to extend the life of roads. Sprayed seals are applied by spraying a film of hot liquid onto a road surface, and then covering with a layer of aggregate.

Bitumen binders can also be modified with the addition of polymers or crumb rubber to provide improved aggregate retention in areas of high stress, or a thicker, more flexible membrane for improved waterproofing and reduction in crack reflection. Multigrade bitumens are another form of modified bitumen for special applications (Austroads 2019b). The inclusion of plastics in the bitumen binder/sealant is being considered in this assessment.

3.2.3 Recycled plastics

Plastics are synthetic materials derived primarily from refined crude oil petroleum products. For most of these materials characteristics such as a high melting temperature, high decomposition temperature and resistance to UV radiation provides benefits, but also means that waste plastic remains in the environment for hundreds of years (White, G. & Reid, G. 2018). It is noted, however that not all plastics that may be used in road infrastructure have these characteristics, as it depends on the proposed use and characteristics needed for the final product.

The plastics most commonly recycled and likely to be reclaimed for use in asphalt products in Australia are (Austroads 2019a):

- Low-density polyethylene (LDPE)
- High-density polyethylene (HDPE)
- Polypropylene (PP)
- Polyethylene terephthalate (PET)

Other plastics include polystyrene (PS), polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), acrylic, nylon, polyurethane (PU), polycarbonates (PC) and phenolic. In Australia, PE, PP, PVC, and PET are the most consumed plastics. Presently PET, PE and PP are recycled most commonly, whereas plastics such as PVC have very low recovery rates relative to consumption, likely associated with toxicity concerns associated with vinyl chloride (Austroads 2019a).

In the literature, where plastics have been used in road pavements (as binder or asphalt modifier), these used HDPE, LDPE and PET. However in Australia, soft plastics were the predominant recycled plastics used in road trials (Austroads 2019a). The Austroads (2019b) report details the availability of these types of plastics in Australia for recycling and reuse, and the benefits of using these materials in roads.

3.2.4 Recycled plastics in asphalt

The reuse of plastics for asphalt products and sprayed seals would require a supply of these materials in a form suitable for use. This assessment has not evaluated the recycling process, or the quality control measures that would be required to produce plastics suitable for purpose.

The percentage of these plastics that may be used in road construction materials is not yet defined, hence this review has focused on available information on products where plastics have been used in road construction materials, which have varying percentages of plastics.

Recycled plastic is incorporated into bitumen, either as an extender or modifier to the bituminous binder, or as a plastic aggregate substitute. The role of the extender is to replace the portion of the raw material to decrease the amount of original material. While plastics used as a modifier serve to enhance the intrinsic characteristics of the final asphalt mixture. Hence, depending on the utility, the mixing of the plastic with asphalt can be done via three distinct processes (Chin & Damen 2019; White, Greg & Reid, G 2018; White & Reid 2019):

1. Wet process of blending the plastic with the bitumen binder at a specific temperature, before being mixed with the aggregates. This is then termed polymer modified bitumen (PMB). By dispersing the plastic in the bitumen under high temperature conditions the binder's physical performance characteristics are changed. These physical changes are comparable to a binder that has undergone polymerisation with virgin polymers. The plastic material is well bound within the bitumen matrix. This process is applicable to plastics with melting points lower than the asphalt mixing process. Depending on the application, the waste plastic can be used alone to lightly modify a base binder for simple applications like spray sealing, or alternatively, the plastic can be combined with, or replace a portion of the virgin polymer that is required in a PMB.
2. Dry process of mixing plastic particles to the crushed aggregates, prior to addition of the binder. This requires a prolonged mixing process to ensure a homogeneous mix is obtained prior to mixing with the binder. This process does not alter the chemical properties of the mixture. A typical dry process would involve the partial fine aggregate replacement with PET (or crumb rubber), which has a melting point significantly higher than the asphalt mixing temperature. This process also has the highest potential for the generation of microplastics as the plastic is present in the aggregates and would wear/age as the asphalt pavement ages.
3. A hybrid process which uses a dry processing method to produce the same or similar outcome as the wet method. In this process the aggregates are heated first, and the recycled plastic and bitumen are then added to the hot aggregates. The plastic creates a thin layer covering the aggregates that is then mixed with the binder.

Not all plastics are suitable for bitumen modification at high temperatures as different plastics have different properties.

Different plastics have different melting points and hence may be used on different ways, which include (Austroads 2019a):

- act as an aggregate extender (or replacement) or asphalt extender
- melt into the bituminous binder and extend it in volume without any performance improvement

- will melt, extend and modify the bituminous binder. This is the most valuable as it calls for an efficient use of waste material which will otherwise become landfill; it reduces the volume of raw material used and improves the overall performance of the resulting asphalt mix.

Low melting point waste plastics are suitable as binder extenders while the higher melting point waste plastics (such as HDPE and PET) are better used as an asphalt or aggregate extender.

When evaluating any recycled material that may be added to asphalt (and/or bitumen), the hazards relevant to the recycled materials needs to understand the key hazards or chemicals identified that would need to be evaluated in relation to worker health and safety and/or environmental risks. This is further presented in **Section 3.3**.

3.3 Hazards associated with recycled plastics

Plastic materials that may be considered for use in road infrastructure have the potential to introduce new hazards or change existing hazards of bitumen and asphalt.

Plastic materials (as described in **Section 3.2.3**) are not explosive or corrosive, however a number of plastics will burn and may be classified as flammable. Under normal conditions, when not exposed to a flame, plastics would not combust.

Plastics, when not heated, are not odorous. However, when heated, plastics can give of odorous and noxious fumes that would need to be considered where plastic is heated in bitumen or asphalt. Plastic pellets or fragments may also have a proportion of dust that may be released to air where disturbed.

The presence of chemicals, as additives or contaminants is a key issue in relation to plastics.

Plastic materials used in most products the basic polymer incorporated into a formulary (plastic compound) with different 'additives', which are chemical compounds added to improve the performance (e.g. during shaping of the polymer, through injection moulding, extrusion, blow moulding, vacuum moulding, etc.), functionality and ageing properties of the polymer. The most commonly used additives in different types of polymeric packaging materials are: plasticisers, flame retardants, antioxidants, acid scavengers, light and heat stabilizers, lubricants, pigments, antistatic agents, slip compounds and thermal stabilisers (Hahladakis et al. 2018).

All the above additives can be mainly divided into the following 4 categories (Hahladakis et al. 2018):

1. functional additives (stabilisers, antistatic agents, flame retardants, plasticisers, lubricants, slip agents, curing agents, foaming agents, biocides, etc.)
2. colorants (pigments, soluble azocolorants, etc.)
3. fillers (mica, talc, kaolin, clay, calcium carbonate, barium sulfate)
4. reinforcements (e.g., glass fibres, carbon fibres).

It should be noted that additives, in nearly all cases, are not chemically bound to the plastic polymer. Only the reactive organic additives, e.g., some flame retardants, are polymerised with the plastic molecules and are becoming part of the polymer chain. It should, also, be noted that substances used as monomers, intermediates or catalysts in plastic manufacturing are not considered to be additives. These, along with any contaminants from the former use of the plastic (if not properly cleaned) may also need to be considered. Where plastic materials are effectively washed prior to use in road infrastructure contaminants from former uses would not be of concern. The processes involved in supplying recycled plastics for use in asphalt and bitumen have not been reviewed in this assessment, however this would need to be reviewed to ensure that the material as supplied is free from contamination (associated with former uses or handling).

When assessing chemical hazards related to recycled plastics, this relates to the presence of contaminants in the materials as proposed to be used, as well as the potential for these chemicals to leach from the materials (when the materials are wet from rainfall and/or other means such as dust suppression or irrigation). The migration of contamination from the materials is a key issue for the use of recycled plastics in asphalt and bitumen.

Review of hazards and risks relating to the various additives (chemicals) that may be in plastics has been undertaken by the Nordic Council of Ministers (Stenmarck et al. 2015), where a large range of chemicals have been identified in plastics. Further review of chemicals in plastics has been undertaken, where the migration, release and fate of chemicals in plastics is considered in more detail (Hahladakis et al. 2018). While much of the focus on the migration of chemicals relates to the contamination of food and drink (where plastics are used as food packaging), reviews have also considered the migration to and impact on the environment, in particular aquatic ecosystems (Hahladakis et al. 2018; USEPA 2016).

When evaluating the leaching and migration pathway the characteristics of the chemicals is important. The chemical needs to be able to partition or leach from the material into water (at neutral pH or consistent with the environment) and the chemicals also need to be soluble in water so that they will migrate with water runoff or infiltration.

The NEPM (NEPC 1999 amended 2013c) indicates the following in relation to the octanol-water partition coefficient (K_{ow}) in relation to the potential for bioaccumulation (and biomagnification) in the environment and the potential to leach from solid materials to groundwater or surface water:

- K_{ow} is the ratio of a chemical's solubility in n-octanol and water at equilibrium.
- K_{ow} is widely used as a surrogate for the ability of a contaminant to accumulate in organisms and to biomagnify. These are often expressed in the logarithmic form (i.e. log K_{ow}). Chemicals with a log K_{ow} value ≥ 4 are considered in this report to have the potential to biomagnify.
- There is a linear relationship between log K_{ow} and log K_{oc} values (K_{oc} is the organic carbon-water partition coefficient). Thus, K_{ow} can also be used to indicate the ability of chemical to leach to groundwater. A log K_{ow} value <2 indicates a chemical has the potential to leach to groundwater and surface water.

Key contaminants derived from plastics that are important for consideration in relation to the migration to and impact on the aquatic environment include: phthalates, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides (OCPs), polybrominated diphenyl ethers (PBDEs), alkylphenols, bisphenol A (BPA), and metals (e.g., cadmium, zinc, aluminium) (Hahladakis et al. 2018; USEPA 2016). Further review of the chemicals expected to be of concern in plastics indicates that most of the above chemicals have a log K_{ow} >2, and are not likely to migrate to groundwater or surface water.

A number, however, are considered to be bioaccumulative, which is particularly relevant where plastic materials are present in waterways including microplastics.

The extent of leaching of additives from plastic and leachate composition is influenced by both the properties of the additive substance and the properties of the plastic polymer, such as the degree of amorphous or crystalline structure (Bejgarn et al. 2015).

Ecotoxicity tests have been undertaken on leachate from plastic products. Review of studies undertaken on 32 plastic products by the USEPA (USEPA 2016) indicated that waterfleas (*Daphnia*) were most affected by the silver within compact discs, plastics from PVC and polyurethane. *Daphnia* 48 hour EC50 values ranged from 5 - 80 g plastic material/L for nine of the tested plastic products; leachate from the remaining plastic products did not demonstrate toxicity to *Daphnia*. Another study identified chemicals from PVC had the potential to compromise feeding and immunity of lungworms. A review of the toxicity of leachate from weathered plastics (Bejgarn et al. 2015) considered leachate from 21 different plastics, which were irradiated with artificial sunlight. Eight of the 21 plastics produced leachate that caused acute toxicity to the marine harpacticoid copepod [Crustacea] *Nitocra spinipes.* Six of the eight plastics causing toxic effects were softer plastics (including PVC) with other materials including polyurethane. Weathering of PVC packaging materials increases the toxicity of leachate. Whether the polymers are amorphous or crystalline in structure seems to be of importance for leachate toxicity. The only (semi-)crystalline plastic that produced toxic leachates was the DVD-case (PP).

Microplastics have also been identified as a key issue in the aquatic environment, along with the physical aspects of plastic litter that affect aquatic life (via entanglement, smothering and ingestion). Issues relating to plastic litter would not be relevant to the use of recycled plastic in asphalt and bitumen (USEPA 2016). As noted above chemicals can also leach directly from microplastics that have migrated to an aquatic environment.

3.4 Key issues relevant to evaluating exposure and risk

In relation to the assessment of exposures for workers, and for the offsite community and environment there are some key characteristics that need to be understood and considered. In particular, whether the inclusion of reclaimed plastics in asphalt or sprayed seals would change existing exposures. To be able to determine this, existing exposures need to be understood, and the product with reclaimed plastic benchmarked against the existing materials.

In relation to asphalt and sprayed seals the following exposures and issues need to be considered:

- Workplace
    - Inhalation exposures – this relates to the characteristics of fume and dust released during preparation and use of recycled plastics in asphalt and sprayed seals.
    - While direct contact may also occur, in particular dermal contact, this is not expected to be of significance in some work areas (and with some products) as workers would be required to wear PPE to minimise exposures.
- Community
    - Inhalation exposures - this relates to the characteristics of fume and dust released during use of asphalt and sprayed seals and the inhalation of these chemicals by the general public. These exposures are lower than for workers as the public would be located well away from the work environment and all fume released to air would be readily mixed and dispersed in ambient air. These exposures only warrant further

        assessment where the data for workplace fumes indicates exposures that are different to existing exposures.
    - Dermal contact – this relates to direct contact with asphalt materials within and beside roadways (principally mixed with soil) following erosion/degradation over time. The public would have little to no direct contact with asphalt pavements on roads (or other areas including pathways). In addition, where asphalt remains a solid material in roads or pavements they cannot be ingested and dermal absorption would not occur.
    - Water exposures – this relates to the leaching of chemicals from the materials, in particular materials that have degraded over time, and these chemicals migrate in runoff or infiltration water to impact on water used for recreational purposes or drinking water, where ingestion and dermal contact are of importance.
- Environment
    - The key issues related to the environment are associated with:
        - emissions to air during preparation and application of the proposed products (which would only need to be further evaluated for the environment where emissions were of concern to community health)
        - leaching of chemicals from the materials (in particular weathered materials) as used in road corridors and migration to aquatic environments
        - generation of microplastics that may move into the environment
        - potential leaching of chemicals from microplastics in the aquatic environment.

To be able to characterise exposures and risks related to the above, information is required on the characteristics of fume and dust generated (and workplace exposures), the composition of soil adjacent to roadways as they degrade over time, leaching of chemicals from the materials (over time) and potential generation of microplastics.

The following sections present further evaluation of these aspects. It is noted that limited information is available in the literature, with most published studies relate to the engineering characteristics of these materials.

It is noted that where the characteristics of the product that includes reclaimed plastic is the same as the traditional product (including no additional chemicals or characteristics that changes exposure concentrations relevant to workers, the community or the environment) then there would be no risk issues of concern that warrant ongoing assessment for the material. This aspect requires benchmarking of the proposed product against the traditional materials.

Section 4. Workplace exposures to fumes generated from asphalt materials

4.1 General

This section provides a review of the available information in relation to workplace exposures to fume derived from standard asphalt materials, and where available, from plastic or polymer modified asphalt materials. This review provides general information on the generation of fume, various workplace activities where exposure may occur, health effects of exposure, guidelines for the assessment of workplace exposures, and data that is available to characterise fume concentrations in the workplace.

In relation to the potential use of recycled plastic in asphalt and sprayed seals, where recycled plastic is incorporated using a wet process, where the plastic (softer plastics with lower melting points) is combined with the bitumen, is of key concern.

Where a dry process is used the plastic would be expected to remain unchanged and fumes from the recycled plastics would not be generated to any significant amount.

Any assessment of workplace exposures should follow existing guidance available from SafeWork Australia.

4.2 Asphalt or bitumen fumes

Asphalt mixes are manufactured by heating and drying mixtures of graded crushed stone, sand and filler (the mineral aggregate) and mixing with straight-run (typically 4–10% by weight), which serve mainly as a binder to hold the aggregate together. At the construction site, the asphalt mix is fed through a mechanical paver machine, which spreads and pre-compacts the mix. The application temperature of the hot mix asphalt is usually between 112 °C and 162 °C (Kalagaeva 2013).

Asphalt (and bitumen) is a solid at standard temperature and pressure. When it is heated, it releases gases (e.g., H_2S and CO_2) and vapours. As the vapours cool, they condense on nuclei to form droplets (aerosols). Fume refers to total emissions that include gases as well as solid particulate matter, condensed vapor (aerosols), and potential some liquid bitumen droplets (refer to **Figure 4.1**). Most of the fume is in the solid particulate phase and condensed vapour suspended in air above the molten product (Kalagaeva 2013). Asphalt/bitumen fume contains PAHs and heterocyclic polycyclic aromatic compounds (Kalagaeva 2013).

Traditionally bitumen or asphalt fume is the material which is measured and reported to reflect the level of potential occupational exposure.

Asphalt fume particles are typically very small in size (97% to 99.7% $\leq 12.5\ \mu m$ [micrometre] diameter) and irregular in shape (Calzavara, Carter & Axten 2003).

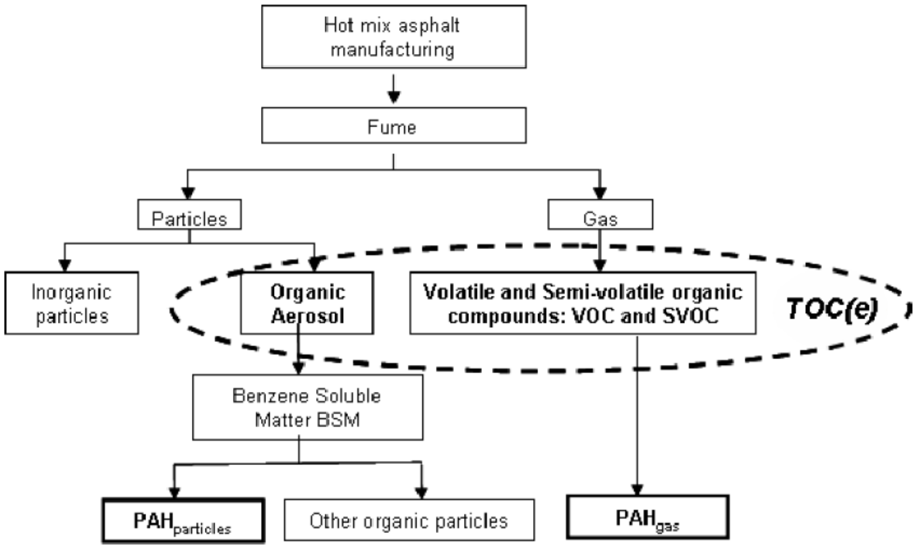

Figure 4.1: Composition of fumes from hot mix asphalt (Gaudefroy et al. 2010)

Asphalt includes a variety of different products having a broad range of different hydrocarbon compositions. The size range of the hydrocarbon molecules in a given type of asphalt greatly affects its viscosity and operating temperatures. The larger the molecules, the greater the viscosity and the higher the operating temperature. However, both laboratory and field studies have demonstrated that, when heated within their operating temperature ranges, the different types of asphalts generate qualitatively similar fume (Calzavara, Carter & Axten 2003). Calzavara et al (2003) indicate that this is not surprising, because all types of asphalts have similar smaller, volatile molecules, and only the smaller molecules can volatilize and re-condense into fume particles.

Emissions will vary depending upon the bitumen source and processing route, but the amount and composition of emissions generated is highly dependent upon the temperature. As a rough guide the amount of fume (particles) emitted from bitumen doubles for every 10 to 15 °C rise in temperature (Kalagaeva 2013).

4.3 Application of bitumen and asphalt

Asphalt and bitumen are laid onto roads by a placement and compaction crew of typically five to ten people. These jobs include paver operators, screed operators, labourers/rakers and roller operators (Kalagaeva 2013). Paver operators (pavers, paving machine operators) drive the paver machine, which receives asphalt from delivery trucks and distributes it on the road in preparation for the roller machine. Screed operators work behind the paver, controlling the even spread of the asphalt mat with a spreading augur before compaction. Mobile rakers work behind the paver, shovelling and raking excess asphalt material to fill in voids and prepare joints for rolling. Labourers often work as rakers, but also handle other tasks that may be more removed from the asphalt fume. Roller operators (rollers) drive the machinery that compacts the asphalt mat and have the mobility to work at varying distances from the paving machine. A foreman may supervise the crew, often coming into close proximity to the screed. In comparison to plant workers, placement and compaction workers have higher potential for exposure to bitumen fume (Kalagaeva 2013)

4.4 Health effects from workplace exposures to asphalt/bitumen fume

The International Agency for Research on Cancer (IARC) has undertaken a review of carcinogenicity in relation to workplace exposures to bitumen and bitumen emissions (IARC 2013). IARC has considered the physical and chemical characteristics of bitumen, bitumen emissions (aerosols, vapours and gases from heated bitumen and products that contain bitumen), occupational exposures (inhalation and dermal exposures) and the available studies in relation to carcinogenicity. This includes a number of occupational/epidemiological studies that have been undertaken to 2010, including a meta-analysis completed by IARC in 1994. In relation to road paving workers, IARC classified occupational exposures to bitumen and their emissions during road paving as possibly carcinogenic to humans (Group 2B) based on inconsistent evidence from occupational studies and inadequate to limited evidence in animal studies. IARC further considered the following from independent studies in exposed workers that support a genotoxic mechanism for cancer in humans from exposure to bitumen.

Following on from the IARC review, an occupational study published in 2015 (Neghab, Zare Derisi & Hassanzadeh 2015) identified significant decreases in pulmonary function and an increase in the prevalence of respiratory symptoms in asphalt paving workers, assumed to be associated with exposure to asphalt fumes (noting that the study adjusted for confounding factors such as smoking). The number of participants in the study was noted to be small, however the outcomes suggest the potential for respiratory effects in these workers.

Petit (Petit et al. 2019) evaluated lung cancer risks associated with exposure to carcinogenic PAHs in a range of occupations. Risks for workers undertaking bitumen and road paving activities were ranked as very low with a low ranking for workers in a tunnel.

There are no epidemiological studies that specifically include workers exposed to asphalt and asphalt products where recycled or reclaimed plastic has been used.

A survey of road paving workers in Australia (Moo et al. 2019) identified that 65% of respondents indicated concern about asphalt or bitumen, with the main concerns relating to fuming and smells. Acute issues experienced by >50% of respondents (or commonly reported) include headaches, sore and watery/irritated eyes, difficulty breathing/coughing. These issues, as well as skin irritation were also identified in other surveys of road workers (Ritta et al. 1996). In the survey 132 of the 152 respondents reported experiencing one or more symptoms or conditions after exposure to bitumen fumes at work. Companies have also indicated they have some reports of health effects in workers, however these are reported infrequently. Some chronic health issues have also been noted, however most of the issues relate to concerns about long-term effects of exposure. Monitoring of asphalt or bitumen fume in Australian workplaces have indicated compliance with the standards. The survey notes that despite compliance health effects are still reported. It should be noted that the current workplace exposure standard does not protect workers against all adverse health effects. The workplace exposure standard is also proposed to be reduced (refer to **Section 4.5**).

4.5 Workplace exposure standard

In relation to workplace exposures, standards are available for what is termed bitumen or asphalt fume. In Australia, Safe Work Australia has a current Time Weighted Average (TWA) standard of 5 mg/m^3 for bitumen fumes. This applies to asphalt bitumen, hot mix bitumen, petroleum asphalt, road asphalt and road tar.

The workplace exposure standard (WES) is based on the standard developed in 1991 by the American Conference of Governmental Industrial Hygienists (ACGIH). In 2001, ACGIH revised the TWA to 0.5 mg/m^3 measured as benzene soluble inhalable aerosol.

Safe Work Australia currently propose to revise the WES to 0.5 mg/m^3 (noting that the existing and draft documentation does not indicate any measurement method, specifically if this relates to benzene soluble inhalable particulate)[1]. The WES is a TWA that relates to exposure concentrations averaged over an 8-hour period.

Review of the measurement methods used for bitumen or asphalt fume by Calzavara et al (2003) indicates that (at the time of their paper) there were no established methods for measuring benzene extractable inhalable particulate. The established methods (used for workplace exposure assessments for over 30 years) relate to total particulate (generally ($\leq$40 µm) rather than inhalable particulate ($\leq$100 µm). Given the small size of asphalt fume (97–99.7% $\leq$12.5 µm), the total method adequately reports asphalt fume.

In addition, the existing methods are also less confounded by the presence of other fine particulates in air (not from fume) which is common on road work sites. Hence the measurement of asphalt fume (analysed using benzene extractable methods) without reference to inhalable is reasonable and consistent with Safe Work Australia. Review by Moo et al (2019) indicates the need for a standardised method for the measurement of asphalt or bitumen fume. The differences in measurement methods needs to be noted where published data is considered.

4.6 Available data on fume

Studies undertaken to evaluate fumes from asphalt report results as asphalt or bitumen fume (as required for evaluating workplace exposures) or provide compositional analysis of the fume. The compositional analysis varies from study to study however a number involve qualitative methods, with very little data available that quantifies individual components of PAHs and VOCs in fume.

The following provides a summary of the limited information available.

Bitumen

Qualitative analysis of bitumen fume (Pirjo et al. 1996) indicates that bitumen fume comprises over 200 individual gaseous and particulate phase compounds, with the main groups being straight chain and branched hydrocarbons, naphthenes, C1-C9 alkyl benzene, naphthalene and C1-C4 alkylated derivatives, phenanthrene and C1-C3 alkyl derivatives, alkylated C1-C4-benzothiophenes and

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[1] https://engage.swa.gov.au/wes-review-release-4/widgets/260877/documents

alkylated C1-C3-dibenzothiophenes. Dibenzofurans, biphenyls, fluorenes, indanes and indenes, pyrene and methyl pyrenes were also identified. Individual concentrations of these compounds are not provided.

Asphalt

Gaudefroy et al (2010) measured fume emissions from bitumen. This study showed that there is some variability in the TOC(e) (refer to **Figure 4.1**) based on temperature and mixes. Higher emissions occurred at higher temperatures, and higher emissions occurred for higher volatile bitumen. Stirring of bitumen resulted in fume emissions, with higher emissions with higher rates of stirring. None of the data presented in this study can be used to characterise workplace exposures or quantify concentrations of individual VOCs or PAHs in air.

In relation to workplace exposures, studies on level of asphalt or bitumen fume in air generally provide short-term monitoring data for specific work activities relevant to road construction. These fume concentrations are typically averages over time periods ranging from <10 minutes to 2 hours. This makes it difficult to compare these levels with an 8-hour average WES. The following summarises some of the available data:

- Data collected from personal air samplers on asphalt plant operators in the US (Calzavara, Carter & Axten 2003) indicate asphalt fumes in the range 0.05 to 0.2 mg/m^3 (benzene extracted). Data from fixed samplers range from <0.05 to 10.5 mg/m^3 (benzene extracted).
- For road construction workers in China (Chong et al. 2018), asphalt fume concentrations range from 0.05 to 6.68 mg/m^3, with the most exposed activities being paver operator, screed worker and raker (where working closely to fresh pavements).
- Maximum bitumen/asphalt fume concentrations for various road construction activities (in the MAK workplace exposure review) (MAK 2012) range from 0.7 to 12.2 mg/m^3, with higher levels reported for work with mastic asphalt (up to 53.2 mg/m^3). Levels of PAHs reported range from 5.6 to 83.6 μg/m^3. Most of the individual PAHs detected relate to the lighter PAH compounds, with fewer detections of the heavier, more carcinogenic PAHs.
- For road workers in Finland (Ritta et al. 1996), mean concentrations were 0.66 mg/m^3 for bitumen fume particulates, 6.8 mg/m^3 for volatile hydrocarbons (total), 0.29 μg/m^3 for particulate PAHs and 5.4 μg/m^3 for vapour PAHs. The highest exposures related to paver operators, screen operators, raker man and manual paver. Polyamines used as adhesion improving agents were not detected.

The above data indicate variable concentrations of asphalt/bitumen fume in air associated with different activities. There are some activities where higher levels of exposure occur, with short-term peak exposures above the WES. Where the existing WES is considered, these peaks may not result in exceedance of the 8-hour average WES, however where the proposed WES (that is 10 times lower) is introduced, these peaks may be of more significance. These would need to be considered and managed for standard asphalt and road activities/materials, as well as where plastic modified materials are used.

Crumb rubber or polymer modified asphalt

Moo et al (Moo et al. 2019) reference a study undertaken in Queensland that found emissions from crumb rubber and conventional polymer modified open graded asphalt are comparable. No specific data is available.

An assessment of the VOC and PAH composition of fume derived from polymer modified bitumen (Porot et al. 2020) involved the sampling of fume from the headspace above standard paving bitumen and polymer modified bitumen (SBS or poly(styrene-butadiene-styrene) polymer). The SBS polymer is found in rubber products that include tires and soles of shoes. The findings of the assessment were as follows:

- For VOCs, the higher the temperature, the higher the concentration of total VOCs. For the polymer modified bitumens, VOCs in air were lower than standard bitumen. This is relevant for all classes of VOCs, but most significant for alkylbenzenes.
- For PAHs, a similar trend in temperature and emissions was observed. For the polymer modified bitumens total PAHs in air were lower than for standard bitumen (lower by a factor of 8 to 20). In particular naphthalene was significantly lower in the polymer modified bitumens.

This is generally consistent with the findings from other studies (Brandt & De Groot 1996; Pirjo et al. 1996), however Ritter et al (2006) noted that nonyl phenols (which are irritants) were detected in the fume of SBS modified hot mix.

Another study (Liang et al. 2017) that evaluated crumb rubber modified asphalt that showed that crumb rubber activated by microwave and trans-polyoctenamer (TOR) reduced levels of PAHs and sulfur compounds in asphalt fume.

Plastic modified asphalt

A summary of issues provided by Austroads (Austroads 2019a) indicates that White (2019) described a fuming generation evaluation test that was developed to analyse binder samples modified with and without recycled plastics. The fuming test showed the presence of toluene and benzene as well as aliphatic, cyclic and aromatic hydrocarbons. These were from normal bitumen rather than recycled plastics. White (2019) concluded that there was no significant difference between the fume samples with and without recycled plastics. The Austroads review infer that fumes from plastic modified asphalt would not be different to what is observed with crumb rubber (and SBS) modified asphalt. Insufficient information is available on the plastic materials used in the testes reported by White (2019). Review by Eurobitume (AI abd Eurobitume 2015) raised concern about heating plastics that contain chlorinated compounds (which include but is not limited to PVC). Hence the nature of the plastic needs to be considered, particularly when the materials are proposed to be heated such that VOCs are emitted to air.

No specific data is available to review what data was collected from these materials.

Plastics and plastic products are well known for producing a range of VOCs. VOCs released to air are higher for plastic derived from waste plastic materials (from recycled materials) compared with new plastic such as polypropylene, polystyrene and LDPE (Yamashita et al. 2009). Higher temperatures of heating resulted in higher levels of VOCs (Yamashita et al. 2007). Another study (Even et al. 2019) showed that softer plastics emit broader and higher levels of VOCs than harder plastics. The characteristics of VOCs released to air where plastic modified asphalt or bitumen are used is not characterised.

Mechanism of fume emissions from modified asphalt

A review of asphalt modified with SBS and polyethylene (PE) considered the mechanism by which these additives may change the fume generation (Xuya et al. 2011). This considered the potential for physical and chemical crosslinking. Adding PE to asphalt showed a suppression of fume generation, with approximately 10% reduction for 1% modified asphalt and 14% reduction for 5% modified asphalt. Similarly, reductions (16% to 20%) in fume generation were observed for SBS modified asphalt. The reasons for the reduction were found to be chemical crosslinking between the polymer molecule and asphalt molecule. This crosslinking plays and important role in reducing asphalt fumes. The study, however, did not evaluate if the composition of asphalt fume had changed.

4.7 Odours

Odours derived from hot bitumen and asphalt is a key issue for road workers and the community who live in the area of such works. These odours are principally aromatics such as benzene and naphthalene or sulfides[2]. Sulfides are responsible for what most people recognise as the smell of asphalt or bitumen. Odours from these operations can be perceived as offensive by some individuals. These odours require management as part of existing road making and maintenance processes.

Information from a survey of Australian workers (Moo et al. 2019) indicates that for 46.2% of respondents fuming and smells from asphalt and bitumen are of concern.

TMR has a Road Traffic Air Quality Management Manual (TMR 2014) that outlines how odours from road construction activities are assessed and managed.

Heating plastics can also result in the generation of odours, that would be different to hot bitumen and asphalt. The combination of heated asphalt/bitumen and recycled plastics has the potential to result in odours that are different to that from traditional materials. No data is available to specifically address the characteristics of odours that may be present from these combined materials. Hence this review has not further evaluated with the existing management measures address potential odour issues that may arise from the use of recycled plastic in asphalt and bitumen.

4.8 Data gaps

The key data gaps that currently exist in the assessment of workplace exposures are as follows:

- The available research relates to specific or known/selected plastics. Reclaimed plastics that are expected to be available for use in road infrastructure are expected to be derived from community and industry recycling programs that provide comingled contaminated plastics that are currently landfilled. No data is available on these comingled plastics.
- Lack of data relating to bitumen/asphalt fume in air for Australian environments where asphalt is utilised. The variability in concentrations needs to be understood for existing workplace environments.

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[2] https://www.boral.com.au/sites/default/files/media/field_document/Asphalt%20in%20your%20community.pdf

- Data on the characteristics, as air concentrations that workers would be exposed to, of fume derived from standard asphalt/bitumen, as well as plastic modified asphalt/bitumen. This would include asphalt/bitumen fume, as well as TRH, VOCs and semi-volatile organic compounds (SVOCs) in fume. Odours relating to plastic modified asphalt/bitumen, with comparison against standard fume, would also be required.
- Information on existing PPE required to manage bitumen fumes in the workplace, and any additional PPE that may be required to address the proposed reduction in the workplace exposure standard. This is important to consider when evaluating workplace exposures to materials that include recycled plastic, where fume and vapour emissions are different to traditional materials.

4.9 Criteria

The key criteria for assessing workplace exposures are the current, and proposed, WES for bitumen/asphalt fume. The current WES is 5 mg/m^3 as a TWA. This is proposed to be reduced to 0.5 mg/m^3 as a TWA.

In addition, it is relevant to also evaluate the characteristics of the fume produced. Hence individual VOCs and SVOCs in fume from standard and plastic modified materials need to be reviewed. For concentrations of VOCs or SVOCs that are statistically different (higher) for plastic modified materials, the individual concentrations should also be compared against WES relevant to each individual compound.

Plastics that contain chlorinated compounds (such as PVC) that are heated pose the greatest risk in terms of the generation of chlorinated VOCs in the workplace that are more toxic (for workers and the community). The concentrations of chlorinated VOCs that may be present in the workplace where such materials (when contained in specific products) is not known due to a lack of data. Given he potential risks posed by these materials it would be appropriate to exclude the use of chlorinated plastics (including PVC) in any road infrastructure.

The management of odours would also need to be considered, where the characteristics of odours from hot asphalt/bitumen change (intensity and/or character) with the addition of recycled plastic.

Section 5. Soil characteristics

Where asphalt or road materials that include sprayed seals degrade there is the potential that these materials would be incorporated into soil that is beside roadways. In addition, where RAP is used, the crushed material may remain as free material beside the road (at times). It is also understood that RAP may also be used as fill. This would only be suitable where the characteristics of the RAP from plastic modified asphalt was no different to traditional RAP or data obtained from testing of the plastic modified RAP reported concentrations that were suitable for use as fill (in various land use settings as may be relevant to the materials). It is noted that where plastic modified RAP is used as fill, where the material is placed at depth the presence of microplastics is not of concern as there is no mechanism for transport to receiving environments. Microplastics require consideration where crushed plastic modified RAP is used as surface materials.

Some data is available from the testing of roadside soil (TMR confidential), where landscaping treatments (including application of compost and soil conditioners) has occurred. The data from these locations is not expected to reflect soil impacts from existing road pavement materials. Rather the data is expected to reflect impacts that may be associated with the application of landscape materials from various suppliers. The data has not been further considered in this review as it is not specific to asphalt/bitumen materials alone. The management of chemicals that may be present in landscape materials (including per- and polyfluoroalkyl substances (PFAS)) is the subject of a separate review and assessment process.

Unless these materials were removed from these locations and placed in areas that may be used for residential, public open space, or commercial/industrial purposes, the soil or crushed RAP would not be accessible for any significant level of exposure for the general public. Should some material be present directly adjacent to paved streets, pathways on footpaths or through open space areas the potential for exposure is expected to be low as the area of soil potential impacted would be very small, and confined to locations close to the paved materials. The suitability of any material, including RAP, for use in such settings should be undertaken separately following all relevant regulatory guidance on the re-use of such materials.

Pavement and soil directly adjacent to pavements within road corridors are not where terrestrial environments are expected or encouraged. Hence there would be no terrestrial risk issues that would require consideration. It is noted that various different environments with a range of terrestrial environments may be present in areas adjacent to the road corridor. Unless the road infrastructure is placed directly within these terrestrial environments and is present in a form that can impact on (or be available to) the terrestrial environment, there is no need to further evaluate potential risks to these environments.

The above would apply to asphalt materials, regardless of the inclusion of recycled/reclaimed plastic, as the risk is mitigated by the lack of exposure to the pavement and the soil directly adjacent to the pavement. For other road infrastructure that may be directly used or placed in adjacent terrestrial environments, the potential for chemicals in the plastics to be available to the terrestrial environment would need to be assessed.

The only mechanism for chemicals in these materials to be of concern to human health or the environment is where leaching occurs, and leachate migrates to a water body (surface water or groundwater). The potential for leaching from these materials is presented in **Section 6**.

Where asphalt materials are removed it is relevant to ensure that the materials do not contain contamination that would classify the materials as regulated waste. Hence the plastic modified material would need to comply with the thresholds in the Queensland *Environmental Regulation 2019* (EP Regulation), Schedule 9, Part 3, Division 2, Table 2 (also included in **Appendix B**). The pH of the material is also required to be between 6.5 and 9.

It is noted that this table includes a threshold for PFAS that is 0 mg/kg. This is not a meaningful threshold as it is not possible to measure 0 mg/kg as all analytical methods have a laboratory limit or reporting (LOR). In practice this threshold would mean no detectable PFAS above the analytical LOR.

Section 6. Leaching from road materials

6.1 Background

This section presents a review of the available information in relation to the leaching of chemicals from asphalt and sprayed seals, and whether this has the potential to be different where plastic is used in these materials.

Leaching of chemicals from materials is undertaken using standardised batch tests. The most commonly used tests in Australia are[3]:

- Toxicity Characteristic Leaching Procedure (TCLP), which assesses leaching under acidic conditions which may occur within a landfill, and hence this test is the default procedure for assessing waste disposal options. This test is not representative of environmental conditions.
- Australian Standard Leaching Procedure (ASLP, as per Australian Standard AS4439), which assesses leaching that is more consistent with environmental conditions. Where the test utilises neural solutions for the assessment of leaching it provides a better measure of what may leach during rainfall. This is the most appropriate test to utilise when assessing leaching from traditional materials and plastic modified materials. Where possible the testing should be undertaken on the materials as expected to be present in the environment in terms of particle size.

Bitumen is not water-soluble. Nor are any substances in bitumen soluble in water. Bitumen and bitumen products have been used for decades is association with the provision of drinking water and stock water, especially for sealing and strengthening dams. Bitumen is also used for roofing applications.

Where recycled plastic is used in bitumen in a wet process, the plastic is 'dissolved', 'partially dissolved' or bound with the bitumen and would not remain present as plastic materials. Hence potential risks relating to the use of recycled plastic from a wet process are expected to be low. However, data is required to verify this outcome.

Where recycled plastic is used in a dry or hybrid process, plastic materials would be bound with the asphalt at application, however this may change over time and with ongoing wear and ageing. The movement of water into these materials and the degradation of the material over time has a greater potential for chemicals that may be present in the recycled plastic to leach and migrate to the environment.

Where asphalt or road pavement (that include bitumen binders and sprayed seals) degrades over time, there is the potential for chemicals to leach from the materials and enter the environment, where it may impact on water quality. The use of reclaimed asphalt paving (RAP) and the presence

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[3] It is noted that batch leach tests provide results that are expected to be conservative, and interpretation of the test is important, refer to WA DER 2015 – Background paper on the use of leaching tests for assessing the disposal and re-use of waste-derived materials

other materials used in asphalt materials (in particular using the dry or hybrid process) has the result in additional leaching.

It is noted that there are numerous studies available on the quality of rainwater runoff from roads and in urban stormwater. These studies capture a wide range of sources of contamination that include the deposition of oil, dust and other materials from vehicles using the roads, urban runoff from residential premises, including runoff water from residential homes, industrial runoff and the atmospheric deposition of pollutants (from regional sources) (Masoner et al. 2019; Müller et al. 2020). The data would also include any leching from the road pavement and sealant materials. Hence in many cases it is not possible to distinguish specific sources from this data. Where information is available that has been able to distinguish sources, it has been included in this review.

6.2 Existing road materials

Existing road materials have been sampled from stockpiles and laboratory sourced road construction materials in a number of locations in Queensland (TMR Confidential report). Analysis of these samples did not identify elevated (above existing health or ecological investigation criteria relevant to a road reserve) levels of metals, BTEXN (benzene, toluene, ethylbenzene, total xylenes and naphthalene) or total recoverable hydrocarbons (TRH (derived from stockpile materials only)). Leaching from these existing materials was not assessed.

6.3 Reclaimed asphalt pavement (RAP)

RAP is the most commonly used recycled material in asphalt. This material relates to milled asphalt pavement that includes contaminants derived from the asphalt material along with those from the vehicles using the roads, and urban dust deposition.

Leach tests have been undertaken on RAP (from stockpiles of RAP) (Townsend 1998) to understand the characteristics of leachate from this material. The material is granular material, not as used in the asphalt roadway, however it does provide an indication of the leaching that may occur from the materials where standard asphalt is degraded.

The following provides a summary of the results:

- RAP materials from 6 different locations in Florida were analysed for leaching, with metals, PAHs and VOCs quantified
- In batch leaching tests (toxicity characteristic leaching procedure [TCLP, acidic leaching], synthetic precipitation leaching procedure [SPLP, neutral leaching] and deionized water leching procedure [DWLP]) the following was reported:
  - no VOCs were detected
  - no PAHs were detected
  - no metals were detected.
- In lysimeter studies simulating unsaturated and saturated conditions over time (up to 40 days) the following was reported:
  - no VOCs were detected
  - no PAHs were detected

- metals were not detected, with the exception of lead where a maximum concentration of 0.0265 mg/L was reported.

The concentration of lead in leachate was noted to decrease over time. Lead was present in the materials as a result of vehicle traffic and emissions (when lead was still used in fuels, which is no longer the case), not from the asphalt road material. This maximum concentration is not of concern for human health or the environment where a 10 fold dilution factor (highly conservative) is adopted.

The report by Townsend (1998) also included a summary of another study that evaluated leaching from hot mix asphalt. The leach study used an acidic leach test (TCLP) and evaluated the presence of metals and PAHs. The study only detected chromium (0.1 mg/L) and naphthalene (0.00025 mg/L). These are low and would not be of concern to human health or the environment where some low level of dilution was considered.

A more recent study relating to RAP (Mehta et al. 2017) included consideration of weathering (UV aging) on the RAP materials (as unbound or crushed material). The analysis included leaching of metals and PAHs from the materials. The study showed that RAP can be used for a range of purposes and there are no risks to the environment, except in highly acidic conditions. The study reported some detections of metals and PAHs in the leachate under simulated rainfall (close to neutral) conditions, however the concentrations were low and not of concern. Manganese and nickel are noted to be the main trace elements leaching from the RAP by rainwater, however the movement of these metals was found to be attenuated by soil. Some PAHs were also detected (including fluoranthene, pyrene, benzo(a)anthracene and chrysene), however the concentrations were low and also attenuated by soil.

A literature review of leaching from RAP was published in 2019 (Herrera 2019). This included information from studies available from 1995 to 2017 (including Mehta et al 2017). The review concluded the following:

- As a source of contamination, RAP is highly variable.
- Some contaminants leached from RAP that exceeded groundwater quality standards (in the US). This included some PAHs. Metals were only elevated at low pH (acidic conditions).
- Leaching occurs with a peak from the first flush of solution, with concentration decreasing over time and flow of water through the material.

The variability of metal and PAH concentrations in leachate should be noted when evaluating leaching from materials that have included plastic in asphalt or bitumen.

In addition, it is important to assess RAP that includes asphalt materials that have been modified by polymers and plastics.

6.4 Leaching from existing pavements/asphalt

As discussed above, assessing leaching from existing pavement or asphalt is confounded by the present of other (often very significant) sources.

A study from the US (Baldwin et al. 2020) evaluated the presence of PAHs in the sediments of Great Lakes tributaries. The study determined that the PAHs reported were most likely derived from coal-tar sealed pavement (dust and sealant products). Note that coal-tar is not permitted to be used in road materials in Australia. The study also considered asphalt (non coal-tar) and determined that this was unlikely or impossible to be the source of PAHs reported in sediments in the environment evaluated.

Coal tar based seals have been identified in runoff and environmental samples collected in other studies (Ames 2018; Kane Driscoll, Kulacki & Marzooghi 2020). Coal tar based seals are no longer used in Australia and hence these studies are not directly relevant to this review.

The asphalt/bitumen materials evaluated in this assessment do not include coal-tar pavements or seals. Where these materials are used, the potential for increased levels of leaching of PAHs into the environment should be considered.

Review (Müller et al. 2020) of a range of urban sources of stormwater contamination notes that studies on bitumen and asphalt show that these materials are not an important source of metals or PAHs in runoff.

6.5 Leaching from modified asphalt or bitumens

Limited data is available for the assessment of leaching from asphalt or bituminous materials (binders and sprayed seals) that have been modified by polymers or plastic.

A review by Austroads (Austroads 2019a) indicates that a study by White (2019) evaluated the leachability of a modified binder by placing nominal 2.5 g samples of binder, with and without recycled plastic, in 50 mL of deionised water for 18 hours at 40 °C. The water was then cold evaporated under nitrogen before the residual was dissolved in 5 mL of ethanol and analysed for mass spectrometry by gas chromatography. This test was not performed according to international test methods but was conducted by a specialised laboratory.

Austroads (Austroads 2019a) indicate that no harmful materials were found leaching out from the modified binder. White (2019) concluded that recycled plastics in roads pose no negative impact to the environment (leachability) and / or workplace safety (harmful fumes).

The Downer website for Reconophalt indicates that leach testing has been undertaken on that product, including the leaching of bisphenol-A (BPA), and the testing has shown no increased environmental risk compared with standard asphalt. The specific test data is not available for review.

Where plastic materials are considered (without inclusion in asphalt or sprayed seals) the key chemicals of concern in relation to leaching include BPA, phthalates, styrene and hydrocarbons.

6.6 Data gaps

Limited leach test data is available for asphalt and bitumen materials. More specifically there is limited publicly available data for leaching from asphalt pavement and road surfaces with sprayed seals in Australia. It is expected that the leachable levels would be variable, and likely to different from materials internationally (due to the source of base products such as bitumen). Hence one of the key data gaps is the variability in leaching from standard asphalt and sprayed seals. This data may already be available with various organisations. If it is available, the data needs to be obtained and compiled. If not available, sufficient number of samples need to be analysed for leaching (neutral) to determine the variability in leaching from these materials.

Leach testing would also need to be undertaken on the plastic modified materials as solids and also as crushed reclaimed asphalt (at the end of the asphalt cycle prior to recycling and reuse). This would need to evaluate leaching (neutral) from sufficient numbers of samples to determine variability. The testing should also consider weathered materials.

All leach tests (standard asphalt and bitumen as well as plastic modified materials) need to be analysed for the same contaminants. This would include metals, PAHs, hydrocarbons (as total recoverable hydrocarbons [TRH] and individual hydrocarbons), BPA, phthalates and styrene as a minimum.

6.7 Criteria

Where testing is undertaken the following criteria should be adopted for the purpose of reviewing the data obtained:

- Leach test results for the plastic modified material need to be compared with the results for standard asphalt and sealant materials. Where there are no differences, then no further assessment is required.
- Where the range of concentrations in leachate are statistically different (higher), then for those chemicals, the concentration should be compared against drinking water guidelines (NHMRC 2011 updated 2018) and default guidelines for fresh water environments (ANZG 2018) that incorporate a 20 fold attenuation factor (leaching to receiving environment). It is noted that the lowest criteria may be from either the drinking water guidelines or water quality guidelines. The 20 fold factor is a default attenuation factor relevant for the attenuation of concentrations in leachate with migration to groundwater or in surface water runoff to a water body (refer to discussion in **Appendix C**). This attenuation factor is consistent with that incorporated in the derivation of ecological investigation levels (EILs) (NEPC 1999 amended 2013c).
- The criteria adopted need to relate to the key chemicals that may be of importance for additives in the recycled plastics.

Section 7. Generation of microplastics

7.1 General

This section presents information available for the assessment of whether the use of plastic in road materials would result in any increase in the generation of microplastics. It is noted that microplastics are generated from existing road surfaces, from tyre and road wear (Järlskog et al. 2020), hence the potential for an increase in the generation of microplastics is of importance in this assessment.

In relation to the potential for the generation of microplastics, the risk is considered to be higher for recycled plastics added using the dry or hybrid processes, where the plastic material remains largely unchanged in the asphalt and can result in microplastics following wear and ageing. Where recycled plastic is incorporated using the wet process, the plastic is more likely to be bound into the bitumen and not available as a plastic to degrade into the environment. Data is required to confirm that these assumptions that drive the risk are correct, particularly in relation to the hybrid process.

7.2 Microplastics issues

Microplastics are generally defined as particles in the size range 1 to 5000 µm (or 1 µm to 5 mm), composed of synthetic polymers with thermoplastic or thermoset properties, elastomers (e.g. styrene-butadiene rubber, SBR), and polymer modified bitumen (GESAMP 2019; Järlskog et al. 2020; Lassen et al. 2015).

Primary micro-plastics consists of plastics which are used intentionally in sizes between 1 µm and 5 mm. Secondary microplastics are formed by fragmentation of large plastic pieces or by wear of paint or plastic sur-faces. Secondary microplastics are formed both by wear of products in use and by fragmentation from larger plastic pieces in the environment (Lassen et al. 2015). Microplastics from road materials, including plastic modified asphalt and bitumen materials are secondary sources.

It is known that plastic has the ability to break down into tiny particles. These particles are better known as microplastics and they can be a huge problem to the environment. If recycled plastics used in pavements are broken down into microplastics and flushed down watercourses into rivers, lakes and seas, then they could increase risks to aquatic environments. This is because they absorb other pollutants such as pesticides and carcinogenic hydrocarbons from the aquatic environment and are often mistaken for food and ingested by zooplankton. Plankton is the foundation of any aquatic food chain and it is not desirable for them to be contaminated by plastics (Austroads 2019a).

There are a number of studies that demonstrate the harmful effects of consumption of plastics. Typical harmful effects are inner and outer lesions and blockage of the gastrointestinal tract, which can lead to a false satiation. With regard to plastics in micro- and nano-size, there are potentially three types of adverse effects associated with ingestion (Lassen et al. 2015):

1. physical effects related to consumption similar to those found for the macro plastics (but for smaller organisms
2. toxic responses from the release of hazardous substances derived from the intended use in plastics or used as raw mate-rial by the production of the polymer
3. toxic reaction to contaminants unintentionally adsorbed to microplastics.

In the absence of the ability to make field observations, researchers used laboratory experiments to investigate the possible effects. There are studies of the biological effects of microplastics in a number of categories of organisms, such as zooplankton, benthic organisms, fish and seabirds, but overall, data is limited. In laboratory experiments, it has been found that microplastics can have a significant negative impact on e.g., food uptake of crustaceans and the eating activity and weight of lugworms. Furthermore, microplastics can cause a form of inflammation in the tissue of mussels. In studies of fish, correlations between microplastics and liver stress, the formation of tumours and indications of endocrine disrupting effects have been observed. Laboratory tests often use relatively high concentrations of microplastics compared to concentrations found in the environment, and the tests only expose very few test animals of a single species compared to the number of species potentially exposed in the environment. Consequently, it is uncertain to what extent the effects observed in the laboratory occur in the environment (Lassen et al. 2015).

There are a number of studies showing that microplastics in the environment contain hazardous substances and/or function as carriers of hazardous substances. In addition, chemicals present in microplastics that have moved into a waterway can leach from the material into the water. There are basically two types of sources contributing to the presence of hazardous substances in microplastics (Lassen et al. 2015):

1. substances intentionally added to the plastics or used as raw materials for the production of plastics
2. substances in the environment adsorbing to the surface of the plastic particles which, over time, may be absorbed into the plastic matrix.

Section 3.3 provides additional discussion on the type of additives that may be of concern for microplastics. Key additives of concern include PBDEs and other brominated flame retardants, nonylphenol, phthalates, metals and BPA. Others such as chlorinated paraffins and biocides may also be present in microplastics in the environment (Lassen et al. 2015).

In relation to persistent organic pollutants (POPs), studies evaluating the role microplastics have as vectors for the bioaccumulation of POPs in marine organisms are mixed as partitioning on and off microplastics can result in different outcomes within the environment (Rodrigues et al. 2019). Commentary (Lohmann 2017) in relation to this issue indicates that there is little evidence that marine microplastics affect the global transport or bioaccumulation of POPs in the oceans. Laboratory studies show that microplastics can be vectors for POPs into organicism however field studies have not supported these outcomes. Hence it is likely that the key issues related to microplastics are due to the physical presence of microplastics in aquatic environments. The leaching of additives in plastics has been previously identified (refer to **Section 6**) as a key issue of concern where additional data is required. Such data would also be somewhat relevant to the leaching from microplastics (if important).

Recent studies indicate that tire and road wear particles (TRWP), may be one of the major sources of microplastics in the environment (Kole et al. 2017; Sommer et al. 2018). The study by Sommer et al (2018) suggest 30% of all microplastics are in waterways are derived from tire wear. Tyres comprise SBR (60%) natural rubber and other additives. When released microplastics settle adjacent to the kerb or in soil nearby, with some transported off-site with runoff. Depending on where road runoff discharges to and if, what level of treatment may occur, they may then be discharged to waterways. The pathways for microplastics from roadways to enter the environment are illustrated in **Figure 7.1**.

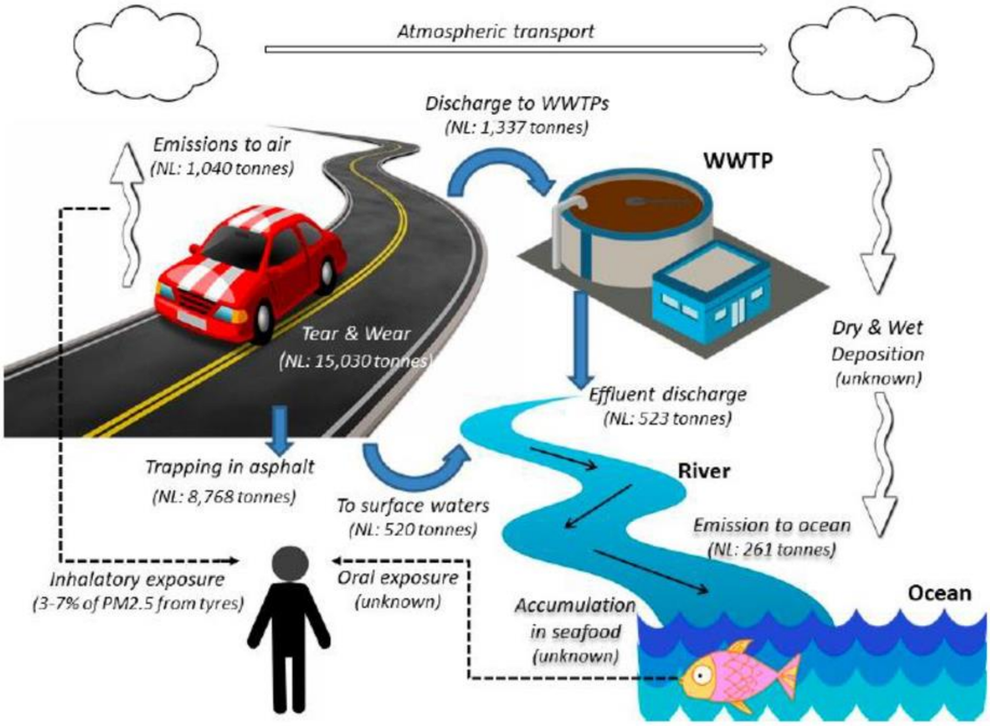

Figure 7.1: Distribution of microplastics from tyre wear and tear to the environment (Kole et al. 2017)

7.3 Microplastics from roadways

Most of the information related to microplastics from roadways are from studies undertaken in Scandinavian countries.

One study (Järlskog et al. 2020) has evaluated the nature of microplastics from roadways in Sweden, i.e. plastics, fibres, paints, bitumen and rubber particles. The study found that the largest proportion of anthropogenic microparticles detected in the samples consisted of rubber and bitumen, which confirms that tire and bitumen microplastic particles one of the major sources of microplastics.

Another study from Norway (Rødland 2019) evaluated road wear particles from polymer modified bitumen (PMB). In PMB asphalt (as evaluated in the study), 3-10% of the bitumen is polymer with the most common polymer used being SBS. The study showed that the shape of tire-wear particles and road wear particles from PMB are similar (elongated round shapes) which are more consistent with sediment particles. In field tests it is not possible to distinguish toxicities related to microplastics from tire wear or from PMB.

A study of microplastics in road dust (Vogelsang et al. 2020) considered polymer modified bitumen wear particles indicate that the particles generated may differ from other asphalt wear particles (particularly where studded tyres are used in winter – not relevant in Australian conditions), however thee is limited data available. Marker chemicals for tracking the impact of tire wear particles in the environment were identified. The concept of identifying marker chemicals for the monitoring of environmental impacts from different recycled materials in asphalt and bitumen products may be worth considering in any studies undertaken.

VTI conducted a literature review of microplastics from tyre and road wear in 2020 (Andersson-Sköld et al. 2020). The literature review considered asphalt and bitumen modified by polymers (which include polyethylene, polypropene, polyvinyl chloride, recycled thermoplastic, SBS, SBR and recycled tyre rubber) noting the most commonly used polymer modified bitumen is with SBS. This review concluded the following:

- The knowledge about microplastics from road traffic is very limited. Only a small number of the existing studies on microplastics relate to microplastics from road traffic, and the ones that do almost exclusively consider tyre wear particles. Studies about particles from the wear of road markings and polymer modified bitumen are almost non-existent. The least is known about the very smallest particles, i.e. the nano (or sub-micron)-sized ones.
- Based on present knowledge and mapping of microplastic sources in Sweden, it can be assumed that at least half of the Swedish microplastic emissions relate to tyre wear particles. Other traffic-related emissions of microplastics include wear particles from the road surface, such as road markings and polymer modified bitumen.
- In urban environments, the majority of the emitted particles end up in stormwater systems. A small proportion of the stormwater is transported to wastewater treatment plants, some of which have been shown to very effectively remove microplastics from wastewater, although there are no studies specifically on tyre wear particles.
- The few studies on effects of microplastics from tyre and road wear have mainly focused on the toxicity of leachates from tyre tread particles. These studies have shown variable results.
- There are large variations in the physical characteristics of microplastic particles from tyres, road markings, and polymer modified bitumen, for instance concerning shape, size, and density. The chemical composition also varies. This, in turn, influences their behaviour and the potential risks they pose to humans and the environment.

In the Netherlands there are two pilot projects currently evaluating plastic cycleways made from recycled polypropylene. While no data is available from the studies, the PlasticRoad website states that the road has a coating that prevents contact between the plastic and vehicle tyres blocking the released of microplastics from the road material (Andersson-Sköld et al. 2020). It is unclear how long this coating lasts, and if long-term ageing removes the coating and allows for the deterioration of the surface and generation of microplastics.

7.4 Data gaps

The review by VTI (Andersson-Sköld et al. 2020) identified that there are significant knowledge gaps regarding: the amounts of microplastic particles emitted as a result of tyre, road, and road marking wear; the sizes of the generated particles; how they spread and potentially change in the environment; at what concentrations they are present in different environments; the extent of human and ecological exposure to these particles; and the environmental and human health hazards posed by microplastics from road traffic.

There are also significant knowledge gaps regarding different methods that can be used to limit the generation of microplastics from road traffic, and their respective effectiveness (Andersson-Sköld et al. 2020).

In Australia, there is no publicly available data on the presence and characteristics of microplastics from roadways. To be able to determine if there are any differences in microplastics from plastic modified asphalt or bitumen products, studies would need to be undertaken on standard materials, and the plastic modified materials. These studies would need to be undertaken using the same methodology to ensure that the data are comparable, and that differences in microplastic generation can be evaluated (if present). The studies would need to review the composition, size and shape if the microplastics from fresh and weathered materials, as well as crushed weathered materials as would occur when asphalt is removed and recycled.

Methods that can be used to routinely and consistently test for the generation of microplastics from various materials are not available and research is required to establish these methods.

7.5 Criteria

There are no criteria available for the generation of microplastics, or the level of microplastics and adverse ecological effects. Hence the criteria that should be adopted would be no statistically significant difference in the generation of microplastics between the plastic modified materials and standard materials, over the lifecycle of the material.

Section 8. Advice and conclusions

This report provides a review of the key aspects relevant to assessing and protecting worker and community health and the environment where recycled plastic is used in asphalt and/or bitumen (including sprayed seals).

When assessing any modified material to be used for road infrastructure, the first stage should be benchmarking of the characteristics of the material against the traditional materials. Insufficient data is available on the traditional and plastic modified asphalt and spayed seals to enable benchmarking to be undertaken in this review. Hence the review has focused on the identification of key risk issues and data gaps. When these data gaps are addressed, benchmarking should be used as the first stage in a detailed assessment.

The risks related to the use of recycled plastics are highest where the recycled plastic is used in a dry or hybrid process as the plastic would remain unchanged within the aggregate and chemicals present as additives (and potentially contamination) to the plastic materials can leach from the materials, and the ageing of road materials may result in the generation of increased levels of microplastics.

Where recycled plastic is used in a wet process it is expected to be chemically bound within the bitumen and would not be available for leaching or the generation of microplastics. The potential for the generation of microplastics over time (with wear and tear) is unknown and may be an issue of concern for the long-term use of these materials.

Insufficient data and information is available on the characteristics of asphalt/bitumen modified with recycled plastic to make conclusions in relation to environmental impacts. There is some information that indicates that impacts (particularly in relation to leachate) are higher where chlorinated plastics may be used. While data is lacking, to minimise potential risks it is recommended that chlorinated plastics should not be used in any road infrastructure.

A number of data gaps have been identified that need to be addressed through data collection to inform the suitability, or otherwise, of recycled plastic in asphalt and bitumen.

The data gaps identified are summarised below:

- Workplace exposures
    - Lack of data relating to bitumen/asphalt fume in air for Australian environments where asphalt is utilised. The variability in concentrations needs to be understood for existing workplace environments.
    - Data on the characteristics, as air concentrations that workers would be exposed to, of fume derived from standard asphalt/bitumen, as well as plastic modified asphalt/bitumen. This would include asphalt/bitumen fume, as well as TRH, VOCs and semi-volatile organic compounds (SVOCs) in fume. Odours relating to plastic modified asphalt/bitumen, with comparison against standard fume, would also be required.
    - Information on existing PPE required to manage bitumen fumes in the workplace, and any additional PPE that may be required to address the proposed reduction in

    the workplace exposure standard. This is important to consider when evaluating workplace exposures to materials that include recycled plastic, where fume and vapour emissions are different to traditional materials.

- Leachate from road materials
    - Limited leach test data is available for asphalt and bitumen materials. More specifically there is limited publicly available data for leaching from asphalt pavement and road surfaces with bitumen seals in Australia. It is expected that the leachable levels would be variable, and likely to different from materials internationally (due to the source of base products such as bitumen). Hence one of the key data gaps is the variability in leaching from standard asphalt and road surfaces (bitumen seals). This data may already be available with various organisations. If it is available, the data needs to be obtained and compiled. If not available, sufficient number of samples need to be analysed for leaching (neutral) to determine the variability in leaching from these materials.
    - Leach testing would also need to be undertaken on the plastic modified materials as solids and also as crushed reclaimed asphalt (at the end of the asphalt cycle prior to recycling and reuse). This would need to evaluate leaching (neutral) from sufficient numbers of samples to determine variability. The testing should also consider weathered materials.
    - All leach tests (standard asphalt and bitumen as well as plastic modified materials) need to be analysed for the same contaminants. This would include metals, PAHs, hydrocarbons (as total recoverable hydrocarbons [TRH] and individual hydrocarbons), BPA, phthalates and styrene as a minimum.
- Generation of microplastics
    - The review by VTI (Andersson-Sköld et al. 2020) identified that there are significant knowledge gaps regarding: the amounts of microplastic particles emitted as a result of tyre, road, and road marking wear; the sizes of the generated particles; how they spread and potentially change in the environment; at what concentrations they are present in different environments; the extent of human and ecological exposure to these particles; and the environmental and human health hazards posed by microplastics from road traffic.
    - There are also significant knowledge gaps regarding different methods that can be used to limit the generation of microplastics from road traffic, and their respective effectiveness (Andersson-Sköld et al. 2020).
    - In Australia, there is no publicly available data on the presence and characteristics of microplastics from roadways. To be able to determine if there are any differences in microplastics from plastic modified asphalt or bitumen products, studies would need to be undertaken on standard materials, and the plastic modified materials. These studies would need to be undertaken using the same methodology to ensure that the data are comparable, and that differences in microplastic generation can be evaluated (if present). The studies would need to review the composition, size and shape if the microplastics from fresh and weathered materials, as well as crushed weathered materials as would occur when asphalt is removed and recycled.

- Standardised and reliable/repeatable tests for the generation of microplastics from various materials need to be developed and applied for traditional and plastic modified materials.

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Appendix A CV for Dr Jackie Wright

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Professional Profile

Jackie Wright has more than 30 years' experience in human health and ecological risk assessment in Australia. Experience includes leading and developing a national risk practice group for a major consultancy, training of staff, providing technical (and toxicological) direction, developing internal technical standards, participating in the development on industry guidance and standards, developing appropriate risk models and providing peer-review.

Areas of expertise include human and eco-toxicological review and evaluation of chemicals in line with Australian regulatory requirements, human health and ecological risk assessment, health impact assessment, impact of exposure to air and noise pollution, exposure modelling, indoor air quality assessment, fate and transport assessment, air dispersion modelling, environmental chemistry, environmental monitoring, and the assessment of air emissions and air toxics. Human health assessments have included a wide range of sites that involve the evaluation of emissions to air, waste sites, residential and recreation areas, operating industrial plants as well as other industrial plants that have been closed and are in the process of property sales or redevelopment and remediation. Ecological assessments have included screening level and detailed assessments of contamination, potential for contamination and remediation of contamination in soil and the aquatic environment. Risk assessments, ecological and human health, have been conducted for review by regulatory agencies (including Contaminated Land Auditors), with Jackie also providing expert support on both human health and ecological risk assessments (including detailed aquatic eco-toxicological assessments) for a number of Auditors in NSW, Victoria, South Australia, Western Australia and Queensland.

Jackie has been heavily involved in the development of national guidance and investigation levels as presented in the National Environment Protection Measure (NEPM) for Site Contamination (2013), CRC CARE Technical Guidance on Petroleum Vapour Intrusion and Silica-Gel Cleanup, Australian Crime Commission Assessment and Remediation of Clandestine Drug Laboratories (2011) and Australian Voluntary Code of Practice, Assessment, remediation and validation: Former clandestine drug laboratories and other methamphetamine contaminated properties.

In addition, she has extensive experience in the assessment of vapour migration and intrusion, detailed evaluation of exposure by occupational, residential and recreational groups including the application of probability distributions to human health risk assessments. Jackie also been involved in a number of key projects that require regular risk communication with interest groups, including resident action groups.

- Toxicological (human and ecological) Review and Assessment
- Human Health Risk Assessment
- Environmental Risk Assessment
- Exposure Assessment and Modelling
- Occupational Exposure Assessment
- Clandestine Drug Laboratories and Public Health Issued from Drug Exposures
- Vapour Intrusion
- Indoor Air
- Health Impact Assessment
- Health impacts of air and noise pollution
- Environmental Chemistry, Fate and Transport
- Risk Communication
- Air Dispersion Modelling

Professional Accomplishments

Toxicology and Risk Assessment

- 2005 to 2023 (ongoing process of development and revision) - Prepared over 50 toxicity summaries for a range of chemicals relevant to the inclusion and assessment of these chemicals within human health and ecological risk assessments in accordance with Australian guidance. Toxicity summaries prepared provide detail on the chemical use, sources, exposures, chemical properties, ecotoxicity (terrestrial and aquatic), environmental fate and transport, health effects, review and identification of appropriate data relevant to acute and chronic exposures by the inhalation, oral and dermal routes, including assessment of carcinogenicity and genotoxicity. Range of compounds assessed includes particulate matter, petroleum compounds, chlorinated compounds, metals and more obscure industry-specific compounds. More specific, detailed review of arsenic dose-response has been undertaken based on current studies.
- 2014-2015 – conducting detailed toxicological review of TCE, particularly in relation to the quantification of inhalation dose-response.
- 2009 to 2013 – provided detailed toxicological review, determination of appropriate dose-response values, and derivation of proposed 2013 NEPM Soil Health Investigation Levels (HILs), including the interim soil gas HILs, and input into the petroleum Health Screening Levels (HSLs). The review included significant update and revision to Schedules B4 and B7 and involved incorporation of all comments from regulators, industry and the public.
- 2009 and ongoing – Detailed review of the toxicity of a range of illicit drugs relevant to the assessment of environmental exposures or public health impacts of exposure to second or third-hand exposures
- 2010 – provided detailed review of toxicological interactions, biomonitoring data and human exposure to metals (and metal mixtures) for a site in Tasmania.
- 2006 to 2023 (and ongoing) - Presentation and collaboration with regulatory bodies in Australia (New South Wales Environmental Protection Authority [EPA], New South Wales Department of Health and Victorian EPA) with regards to the approach adopted and information presented with toxicity summaries (addressing human health and aquatic toxicity where required) for key, high profile assessments.

Exposure and Risk Assessment (Human Health and General Environmental)

- 1992 to 2023 (ongoing) - Project management and evaluation of human health and environmental risks associated with over 350 contaminated sites in all states of Australia utilising national guidance that include NEPM, enHealth, ANZECC and NH&MRC guidance. Sites include operational sites as well as other industrial areas proposed for redevelopment for industrial, recreational or residential use. Most of the sites assessed are associated with petroleum contamination, chlorinated hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and metals. Other sites include those impacted with dioxins, phthalates, PCBs and PFOS/PFOA.
- 1995 to 2023 (ongoing) - Detailed assessment and ongoing evaluation of risks to human health associated with contamination issues derived from the Orica Botany site in Sydney. A number of assessments have been undertaken over a period of 17 years and has involved detailed review of risks to residents (including groundwater extraction and use), workers and recreational users of a large area affected by the discharge of contamination in shallow and deep groundwater to surface water within a drain and an estuary, historically deposited sediments and volatile chlorinated compounds in air. The assessment of risk has been tied closely

with ongoing monitoring with detailed exposure reviews, including the collection of additional data and ongoing review of methods, being undertaken for many key aspects of the project. The process required evaluation within context of the NEPM (1999) and enHealth (2002) guidance with regular liaison with the NSW OEH, NSW Department of Health and independent reviewers.

- 2009 to 2015 - Derivation of national guidelines for the investigation and remediation of clandestine drug laboratories in Australia. The work involved the derivation of investigation levels, protective human health and the environment (terrestrial and aquatic), associated with former clandestine drug laboratories in Australia. Project required identification of key indicator compounds from over 200 base, intermediate and waste products that may be associated with over 20 different drug manufacturing methods. This required consideration of human health and environmental toxicity, behaviour/fate and transport in the environment and manufacturing methods. Guidelines were derived for indoor surface residues, indoor air, outdoor soil and the environment (local waterways and soil) for residential, commercial and recreational areas. The guidelines developed have been published by the Australian Government in April 2011. Further development of state guidelines, such as those from NSW Health have been undertaken to 2015.
- 2019 – Development of Australian Voluntary Code of Practice, Assessment, remediation and validation: Former clandestine drug laboratories and other methamphetamine contaminated properties, as published by Environmental Health Australia. The publication of these guidelines ahs included a range of workshops to share information and better understand issues and data gaps in the management of drug affected properties.
- 2017 to 2023 – Review of a range of issues relating to exposures to illicit drugs by the public and provision of expert advice to understand exposure, toxicity and potential for adverse effects.
- 2010 to 2023 – Detailed evaluation of community exposures and risks to PM10 and PM2.5 derived from urban (combustion) sources as well as crustal (mining) sources. A number of urban projects have been completed, including major road infrastructure projects such as NorthConnex, WestConnex M4 East, WestConnex New M5, WestConnex M4-M5 Link, F6 Stage 1, Western Harbour Tunnel, Beaches Link and Great Western Highway in NSW and West Gate Tunnel and North East Link in Victoria and rail infrastructure projects including the Moorebank Intermodal Terminal and Botany Rail Duplication in NSW and the Suburban Rail Loop East in Victoria. These infrastructure projects have involved the development and researching of appropriate methodologies for the assessment of particulate exposures, with particular focus on community exposures and risks. The work has also considered detailed assessments related to other criteria pollutants that include ozone, nitrogen oxides, sulphur dioxide, particulate matter and other combustion products (such as polycyclic aromatic hydrocarbons and volatile organic compounds). Projects have involved detailed review of current literature in relation to the health effects and the identification and use of appropriate dose-response relationships relevant to the quantification of relevant health endpoints, with consultation conducted with stakeholders, including state health departments and the community. Works undertaken for the West Gate Tunnel, North East Link and Suburban Rail Loop East included the panel inquiry (presentation and attendance at the inquiry).
- 2018-2019 – Detailed assessment of particulate risks associated with power station emissions, including detailed critical peer review of public commentary papers as well as published papers and the available research underlying current understanding of health impacts from changes to particulate matter in urban and rural air environments.

- 2010 to 2023 – Detailed assessment of health impacts associated noise, as generated from major road or rail infrastructure or from aircraft noise. These assessments require an understanding of various noise guidelines, as well as current literature on the health effects of noise on the community. Assessments have included qualitative, semi-quantitative as well as quantitative assessments of risk and population incidence utilising published exposure-response relationships.
- 2016 to 2018 – Detailed assessment of roadway and tunnel design features to ensure public health is protected. This has included assessment of exposures to nitrogen dioxide and the build-up of carbon dioxide (in-cabin) in long tunnels, design of long tunnels to ensure public safety from fatigue and monotony and design of roadways to ensure flicker effects do not adversely affect road users.
- 2015 to 2023 – conduct of detailed human health and ecological risk assessments for a range of sites (in particular airport and defence sites) where PFAS issues are of potential concern both on the site and in relation to offsite migration, discharge and exposure. Work has involved detailed evaluations and the development of site-specific guidelines and management measures within the context of a moving regulatory environment.
- 2020 to 2023 – Detailed assessment of risks to human health and the environment in relation to the proposed reuse of materials in road infrastructure (considered a wide range of materials proposed for reuse, in a variety of use scenarios).
- 2008 to 2014 - Detailed evaluation of human health and environmental issues associated with a former chlor-alkali plant. The assessment involved detailed evaluation of mercury fate and transport with use of specialised data collected and analysed by CSIRO and liaison with experts on mercury issues from the CSIRO. Assessment considered environmental issues associated with the presence of mercury in groundwater and discharge to an urban (highly modified) environment, as well as issues associated with mercury (elemental and inorganic) in soil and groundwater with respect to fate and transport, human health and environmental issues.
- 2010 to 2015 (with ongoing advice to 2023) – Conduct of a detailed Health Impact Assessment in relation to major rail infrastructure development proposal at Moorebank. The HIA involved consultation with stakeholders, in particular local councils, NSW Health and the community, with all aspects of the proposal being address in relation to health impacts, both positive and negative. The HIA was peer reviewed by the University of NSW and an international expert. Ongoing advice relates to construction and operational management of PFAS.
- 2016 to 2018 – Literature review and assessment of community health impacts associated with landfill gas emissions, and emissions from water to energy facilities.
- 2018 to 2023 – Conduct of a number of detailed human health risk assessment or health impact assessments in relation to the proposed development of waste-to-energy facilities in NSW, Victoria and Queensland. A number of the projects have been approved.
- 2011 – Quantitative assessment of risks to human health associated with the placement of remediated soil that contains residual levels of radiological contamination, beneath a proposed commercial/industrial development in South Australia.
- 2011 to 2016 – Detailed evaluation and development of chemical risk assessments for a range of products/compounds utilised during coal seam gas operations in NSW and Queensland.
- 2017 to 2018 – Panel member on the WA Government Technical Enquiry on hydraulic fracturing.
- 2011 – Development of a detailed scope of works for the assessment and remediation of an abandoned asbestos mine in NSW. The works required

collaboration between key stakeholders including NSW Health and the NSW EPA with the focus of the works on the protection of off-site community health.

- 2011 to 2023 – Assessment of risk issues associated with the presence of friable and bonded asbestos materials on a range of sites, proposed to be used for residential, school or commercial/industrial purposes. The assessments include consideration of risk management measures required, monitoring requirements and establishing site specific criteria relevant for the protection of construction workers and off-site residents (as required).
- 2010 – Detailed assessment of risks (including detailed assessment of toxicity of individual compounds and mixtures) to human health associated with the presence of nitrate, nitrite and perchlorate contamination in drinking water (international project).
- 2009 to 2023 (and ongoing) – Expert support for contaminated land Auditors located in New South Wales, Victoria, Queensland, South Australia and Western Australia. Expert support has included review of human health and ecological risk assessments for a range of projects and issues.
- 2000 to 2023 - Detailed evaluation of risks to human health and the environment associated with redevelopment of large a number of gasworks sites in New South Wales and Victoria. Projects have involved the evaluation of the vapour migration pathway, including the collection of relevant soil gas and vapour emissions data to quantify exposure consistent with the proposed developments. The process required liaison with relevant site auditors, Vic EPA, SA EPA, NSW EPA and NSW Department of Health as required.
- 1995 to 2023 - Detailed evaluation, modelling and risk assessment of a number of landfill and waste depots in Australia (in New South Wales, Australian Capital Territory, Queensland and Victoria). This includes proposed waste destruction technologies, proposed waste depots and landfills, operational landfills, composting operations and closed landfills with assessments considering workers, residents and recreational users of the site and surrounding areas. Assessments undertaken have considered issues associated with the presence of a wide range of chemicals, landfill gas emissions, leachate generation and leaks, stormwater management, bioaerosols and other pathogens and bacteria.
- 1995 to 2023 (ongoing process as vapour issues are relevant for many projects) - Evaluation of vapour migration (and vapour intrusion) from numerous sources including contaminated soils and groundwater (dissolved phase and free phase) for many different chemicals, and subsequent assessment of human health risks associated with the estimated vapour concentrations. In addition, Jackie has developed and managed various techniques for the direct measurement of vapour migration in residential, recreational and industrial settings as part of the risk assessment process.
- 2009 to 2023 - Detailed evaluation of public health issues associated with recreational exposures to arsenic, lead and/or PAHs in surface soil in primary/secondary schools, sporting areas and children's playgrounds. Provision of technical advice along with appropriate general advice relevant for presentation to the public and responses to questions from the general public.
- 1995 to 2021 - Evaluation of human health risks associated with potential exposure to emissions from coal mining activities, including the assessment of potential risks and health effects associated with exposure to fine particulates.
- 1998 to 2009 - Evaluation of human health risks associated with the existence of, and potential remediation of encapsulated scheduled waste materials located near residential and recreational areas. The assessment has involved ongoing monitoring, review of toxicity and exposures on an ongoing basis, review of remediation options and risks derived from the application of preferred remediation options. The encapsulation has now been remediated.

- 2007 to 2013 – Assessment of risks to human health and the environment associated with the re-use of water (including irrigation uses) from a groundwater treatment plant located in Sydney.
- 2000 to 2005 - Evaluation of human health risks associated with a number of contaminated sites located in Abu Dhabi, Spain and Azerbaijan. These risk assessments involved assessment of human health risks using USEPA guidance as well as WHO guidance.
- 2005 to 2023 - Project management of large human health risk assessment associated with the redevelopment of explosives and munitions factories and firing ranges within various areas of NSW and Victoria.
- 1995 to 1998 - Evaluation of human health risks associated with off-site accumulation of lead from historical deposition associated with a former operating lead paint site located within a residential area in Sydney. Project involved the review of lead exposure and toxicity, identification and agreement to lead action levels relevant for residential properties located close to and further away from the former source.
- 1995 - Evaluation and coordination of a multi-pathway health risk analysis for a large contaminated site in Sydney involving the use of probabilistic risk assessment methodology.
- 2000 to 2005 - Conducting a feasibility assessment for a waste destruction facility in Sydney, using a probabilistic risk assessment methodology. Conduct of a detailed health risk assessment associated with the operation of the selected technology, including presentation to the Commission of Enquiry. Subsequent review of the process and exposures in relation to placing the facility within a rural area (as opposed to an urban area) and consideration of other multi-pathway exposures.
- 1993 - Assessment of risks to human health and the environment associated with sewage sludge incinerators at North Head and Malabar Sewage Treatment Plants.
- 1992 to 2023 (and ongoing) - Determination of preliminary remediation goals for numerous contaminated sites based on risk criteria.
- 1995 to 2023 (and ongoing) - Development of air sampling procedures and techniques to collect air data relevant to the further assessment of vapour migration pathways in a range of areas. This includes the collection of ambient air, soil gas data (active and passive and sub slab) and flux emissions.

Ecological Risk Assessment

- 1998 to 2023 (ongoing) - Derivation of risk-based criteria for a range of projects that are based on the protection of the aquatic environment. Evaluations have considered the potential for physical parameters (turbidity, pH, dissolved oxygen) and contaminants (principally metals, polycyclic aromatic hydrocarbons [PAHs], PFAS, petroleum compounds and chlorinated compounds). The evaluations include the potential for contaminants to leach from soil, migrate to groundwater and potentially discharge to a receiving environment (considered both marine and freshwater [including ephemeral] systems). Some of the assessments have required review and consideration of fate and transport modelling.
- 2009 to 2023 (ongoing) – Identification and derivation of investigation levels protective the terrestrial and aquatic environments associated with former clandestine drug laboratories in Australia. Ecological Tier 1 levels (based on available ecotoxicological data primarily from overseas studies) were identified and proposed for use in remediation guidelines with additional guidance provided in relation to sites where more detailed assessments of environmental risk issues needs to be conducted.
- 2010, 2011 and 2012 – Conduct (co-presenter) of lectures at the University of Sydney for the Risk Assessment (Human Health and Ecological) module for

undergraduates, School of Geosciences. Ecological risk assessment lectures addressed basic principles and frameworks, stressors, fate and transport, bioaccumulation, uptake, derivation of ANZECC Guidelines, reviewing available ecotoxicological studies and conduct of statistical analysis using the CSIRO Burrlioz software for establishing water guidelines.

- 2010 to 2011 – Expert witness in relation to ecotoxicological impacts of initial works proposed for the Barangaroo site in NSW.
- 2010 - Assessment and derivation of water criteria for petroleum hydrocarbons relevant to the protection of the terrestrial and aquatic environments from the reuse of urban run-off for irrigation or a public park and associated runoff into a lake. Assessment required a detailed assessment of not only phytotoxicity, but levels at which grass growth would be affected to the extent by which grass cover on an important AFL playing field would be affected.
- 2009 to 2011 – Detailed review of screening level risk ecological assessment (supporting studies and outcomes) for the discharge of contaminated groundwater into a sensitive marine environment in South Australia. Review required detailed consideration of the local environment, consideration that appropriate ecological indicator species have been selected, consideration of the range of urbanisation stressors within the environmental and potential for groundwater discharges to result in adverse effects to the aquatic environment, over and above those from urbanisation.
- 2008 to 2010 - Detailed evaluation of environmental fate and transport issues associated with a former chlor-alkali plant. The assessment involved detailed evaluation of mercury fate and transport with use of specialised data collected and analysed by CSIRO and liaison with experts on mercury issues from the CSIRO. Assessment considered ecotoxicological risks associated with the presence of mercury in groundwater and discharge to an urban (highly modified) environment.
- 1992 to 2023 (and ongoing) - Determination of preliminary remediation goals for numerous contaminated sites based on risk criteria. In relation to environmental risk issues, this has included the identification of appropriate and screening level criteria that are protective of fresh and marine environments and phytotoxic effects. Where necessary more detailed evaluations of ecotoxicological effects have been considered. This has included the design of suitable surveys and sampling programs (including microtox, microalgae, fish, crustacean, amphipod (sediments), plant and earthworm), interpretation of information and data from these studies, discussion of results with relevant regulatory parties, uncertainty analysis and reporting. These studies have been conducted for the assessment of petroleum hydrocarbon, cyanide, inorganics, ammonia, chloride, phosphorous and nitrate concentrations in soil and discharges from groundwater.
- 2000 to 2008 - Detailed evaluation of risks to human health and the environment (particularly aquatic species and sediments) associated with redevelopment of large a number of gasworks sites in New South Wales and Victoria. The project in NSW involved collaboration with sediment experts to determine the nature and extent of sediment contamination, potential for adverse ecotoxicological effects and requirements for remediation. The process required liaison with relevant site auditors and the DECCW (formerly NSW EPA) as required.
- 2007 - Assessment of risks to terrestrial and aquatic (marine water) environments associated with the re-use of water from a groundwater treatment plant located in Sydney. Water is proposed to be reused for a range of proposes that include industrial water (where it may be directly discarded to the marine environment) and irrigation where the water may affect terrestrial species and runoff may enter local water ways. The assessment considered available ecotoxicological data and guidelines available from Australian and International studies (where relevant to Australian species).

Contaminant Transport

- All of the projects listed above have involved the assessment of contaminant transport in at least one media. More specific examples are listed below:
- Vapour partitioning and transport assessed for petroleum compounds, including the development of a national database of petroleum vapour data, related to over 300 petroleum impacted sites, and detailed review of the database in conjunction with technical specialists from the USEPA. The database developed has been peer-reviewed by the USEPA and has been incorporated into the USEPA technical review of data from both the US and Australia for the purpose of determining screening distances.
- Vapour partitioning and transport assessed for chlorinated compounds at numerous contaminated sites, including the assessment of vapour risk issues at the Orica Botany site from 1994 to 2022.
- Review and use of groundwater fate and transport modelling conducted in support of numerous detailed risk assessment outcomes. Reviews have been conducted for the purpose of ensuring these models adequately address the potential movement of contaminants from a source to a point of discharge, utilising appropriate inputs and site data.
- 2008 to 2014 - Detailed evaluation of mercury fate and transport in groundwater and air (mercury vapour) with use of specialised data collected and analysed by CSIRO and liaison with experts on mercury issues from the CSIRO. Assessment considered environmental issues associated with the presence of mercury in groundwater and discharge to an urban (highly modified) environment, as well as issues associated with mercury (elemental and inorganic) in soil and groundwater with respect to fate and transport, human health and environmental issues.

Air Emissions and Vapour Assessment

- Jackie Wright is experienced in all aspects of determining air quality, including monitoring, assessing and modelling soil gas, vapour emissions and emissions from stacks and other fugitive sources. Projects include analysing dust emissions from a number of quarries and coal mines, motor vehicle emissions; modelling vapour emissions from motor vehicles and sources such as creeks, ponds and waste areas; and assessing odour emissions from sewage treatment plants.
- 2020 to 2023 – Assessment of inhalation exposures to drug residues derived from contaminated materials and within properties, prior to and post remediation.
- 2012 to 2013 – Development of petroleum vapour intrusion guidance for Australia in conjunction with CRC CARE. The project has involved the development of clear, prescriptive guidance that incorporates current science on the assessment of petroleum vapour intrusion. The guidelines being developed have been presented at a series of PVI training workshops (supported by ALGA and CRC CARE) run in Sydney, Melbourne and Perth.
- 2009 to 2023 (ongoing) - Development of a petroleum vapour database to assist in the interpretation and understanding of the behaviour of petroleum vapours in the subsurface environment. The database is unfunded and independent and has been interpreted by Jackie as well as industry experts in Australia and the US. The database has been peer-reviewed by the USEPA, and incorporated into the USEPA publication on the use of field data (from the US, Canada and Australia) to support and develop vertical exclusion/separation distances (refer to the following website for the USEPA review and access to the database developed: http://www.epa.gov/oust/cat/pvi/). This data is being used to support the development of screening distances that are being incorporated into guidance being developed in Australia and the US.

- 2005 to 2023 (ongoing) - Preparation of conceptual site models and completing screening level modelling (using published models such as Johnson & Ettinger) for the assessment of vapour migration and intrusion issues on a wide range of sites (over 200) affected by petroleum and chlorinated hydrocarbons.
- 2010 to 2023 – Detailed evaluation of community exposures and risks to PM10 and PM2.5 derived from urban (combustion – associated with road and rail infrastructure) sources as well as crustal (mining) sources. A number of urban projects have also considered community exposures and risks to other criteria pollutants that include ozone, nitrogen oxides and sulphur dioxide. Projects have involved detailed review of current literature in relation to the health effects and appropriate dose-response relationships relevant to the quantification of relevant health endpoints, with consultation conducted with stakeholders, including state health departments.
- 1995 to 2023 (ongoing) - Development of methods and approaches for the sampling and assessment of vapour (e.g. soil gas, flux emissions, indoor and ambient air). Works conducted has involved the conduct of field activities for the purpose of collecting this data.
- 1995 to 2023 (ongoing) - Interpretation and assessment of vapour data for the purpose of characterising inhalation exposures in a range of scenarios. These include existing buildings and proposed developments.

Risk Communication

- 2000 to 2023 (ongoing) - Jackie Wright has experience in the preparation and presentation (communication) of risk outcomes from a number of key projects across Australia to a range of community groups. These groups include workers and unions, residents and community action groups. Successful communication with stakeholders and the community on controversial projects including infrastructure, coal seam gas and other mining projects has been required.

Air Quality Assessment

- 1990 to 1995 – Air dispersion modelling and air quality impact assessment conducted for various mining (coal mining and quarry activities) and transport (major roadways) in NSW and Victoria. Projects included the development of emissions inventories, setting up and running air dispersion models and reporting.
- 2011 to 2015 - Air dispersion modelling conducted for the assessment of exposures (and risks to human health) to crop, grain and timber fumigants. The assessment have been undertaken based on trial data, with scaling to address commercial application.
- 2010 to 2018 - Air dispersion modelling conducted for the assessment of exposures (and risks to human health) to grain fumigants, timber fumigants, hydrogen sulphide, chlorinated compounds, silica and dust (particulate) emissions from a range of facilities. Modelling has been conducted using Screening level and mode detailed Ausplume and Calpuff dispersion modelling packages.
- 2010 to 2023 - Review of air dispersion modelling undertaken for a range of projects. The reviews have been undertaken to determine if the assessments are adequate for the purpose of understanding and characterising community health impacts. In some cases, the review has been undertaken as part of a larger assessment of public health impacts. Projects have included communication of the air quality assessment and health impact assessment to community groups.

Noise Impact assessment

- 2019 to 2022 - Systematic review of health impacts of transport noise for Waka Kotahi NZ Transport Agency in New Zealand. The work has involved a detailed systematic review of the evidence in published and grey literature in relation to the health effects of transport noise (road, rail and air) and whether the evidence is sufficient to support quantification of health impacts using exposure-response functions. The review has considered recent literature and the GRADE system of review to establish the robustness of the available publications and strength of evidence. This review considered the most recent reviews completed by the WHO and enHealth in 2018.

- 2014 to 2021 - Detailed Evaluation of Community Exposure and Risk to impacts associated with transport infrastructure projects for Transport for NSW and Transurban/Western Distributor Authority/ North East Link Authority in Victoria, Australia. Health impact assessments have included a detailed assessment of impacts from noise during construction and operation. This included a detailed review of current science in relation to health impacts of construction noise, as well as road transport noise sources. In some assessments quantitative risk assessment was required to be undertaken to address impacts on community health. Projects have included: NorthConnex (road - NSW); WestConnex projects - M4 East, New M5, M4-M5 Link (road - NSW); F6 Stage 1 (road - NSW); Gateway project (road and rail – NSW); Western Harbour Tunnel and Beaches Link (road - NSW); West Gate Tunnel (road -Victoria); North East Link (road – Victoria).
- 2016 to 2017 - Brisbane Airport Corporation, Queensland, Australia. Conduct of a review of the health impacts of aircraft noise as these relate to the identification and use of exposure response relationships for assessing health impacts, particularly related to flight paths near major airports.

Expert Witness

- Long Term Containment Facility at Nowingi, case presented in VCAT. The proponent was Major Projects Victoria, approvals application WA58772.
- Lend Lease (Millers Point) Pty Ltd and Orsats Australians for Sustainable Development Inc., Land and Environment Court Proceedings, 40965 of 2010 (NSW).
- Seppanen&Seppanen v Ipswich City Council, Minister for Economic Development Queensland and Queensland Urban Utilities (2016).
- Westgate Tunnel Project, Expert Witness, Inquiry and Advisory Committee (IAC) hearings (Victoria, August-September 2017).
- Child care centre project, Provision of advice as expert witness for ACT Government Solicitor (2017).
- Caltex Petroleum Pty Ltd v Campbelltown City Council Environment, Resources and Development Court Proceedings No 258 of 2015 (2017 to 2019) (SA).
- North East Link Expert Witness, Inquiry and Advisory Committee (IAC) hearings, Expert Witness (Victoria, 2019).
- Clermont Quarries Pty Ltd v Isaac Regional Council, ECL Dalby Pty Ltd, Chief Executive, Department of State Development, Manufacturing, Infrastructure and Planning and Environment Court (Qld), Expert witness (2019 - 2020).

Teaching

- 2010 to 2012 – Conduct of lectures at the University of Sydney for the Risk Assessment (Human Health and Ecological) module for undergraduates, School of Geosciences.
- 2009, 2010, 2012, 2013 to 2022 – Conduct of lectures at the University of Technology Sydney as part of the Contaminated Site Assessment and Management (CSARM) Professional Development Short Course, Risk Based Site Assessment.

- 2020 and 2022 – Toxicological Risk Assessment lecture to UNSW School of Business.
- 2017 – ALGA Risk Assessment Training Course: New Zealand
- 2014 – ACLCA (Qld) Training Course on Vapour Intrusion and Landfill Gas Assessment (organising and teaching) – May 2014
- 2014 and 2015 – ACLCA (SA and VIC) Training Course on Vapour Intrusion (teaching) – June 2014.
- 2013 and 2015 – ALGA Training Course on Vapour Intrusion (teaching).
- 2013 and 2015 – Vapour Intrusion Short Course. Training Course conducted at CleanUp 2013 and 2015, CRC CARE (teaching).
- 2016 – Clandestine laboratories – risk assessment (teaching) ALGA and ACTRA (separate workshops)
- 2014-2018 – Short courses/branch forums for ALGA – various issues regarding PFAS assessment, vapour intrusion, bioaccessibility methods, clandestine laboratories
- 2016 and 2018 – Short course for WasteMINZ – bioaccessibility methods
- 2010-2011 – Basic and Advanced Risk Assessment Course for Queensland Branch of the Australian Contaminated Land Consultants Association

Work History

Principal/Director/ Owner	Environmental Risk Sciences Pty Ltd	2008 (current)
Adjunct Lecturer	Flinders University	2016 (current)
Principal Environmental Scientist	URS Australia, North Sydney, NSW (formerly Woodward-Clyde)	1992 to 2008
Project Engineer	Sydney Water, Sydney, NSW	1991-1992
Environmental Scientist	Nigel Holmes & Associates, Sydney NSW	1990-1992
Assistant	Dames & Moore, Crows Nest, NSW	1988-1990

Education

BE (Hons)	University of Sydney, Bachelor of Engineering (Hons)	1989
PhD	Public Health, Health and Environment, Flinders University	2016

Professional Accreditation

Fellow of the Australasian College of Toxicology and Risk Assessment (ACTRA)

Professional Development

American College of Toxicology - Virtual Advanced Comprehensive Toxicology Online training course (25 modules) (2021)

Invited member of task force - WA EPA scientific inquiry into fracking in WA (2018)

Clandestine laboratory safety and investigator training and synthesis run by the Clandestine Laboratory Investigators Association (8-hour course, 2011)

Ecological Risk Assessment Course run through AEHS and credited by University of Massachusetts Boston (2010)

Mid-America Toxicology Course (35 hours, 2010)

Dose-Response Boot Camp run by Toxicology Excellence for Risk Assessment (TERA) (5 day course, 35 hours, 2008)

Vapor Intrusion Assessment and Mitigation Short Course run by Air & Waste Management Association (4 hours, 2006)

USEPA Human Health Risk Assessment Short Course (24 hours, 1995)

Affiliations

Member (former committee member, remains co-opted committee member), Australasian College of Toxicology and Risk Assessment (since 2007).

Member, Australian Land and Groundwater Association (since 2010).

Clean Air Society of Australia and New Zealand (re-joined 2015)

Member, Environmental Health Australia (since 2011).

Member, SETAC (Asia Pacific) (since 2011).

Member, Air & Waste Management Association (since 2006).

Member, Society for Risk Analysis (since 1997).

Member, Association for Environmental Health and Sciences Foundation (since 1997).

Awards

2020: Winner of Best Case Study (principal author), Australia New Zealand Policing Advisory Agency and National Institute of Forensic Science

2017: Winner of Best Case Study (principal author), Australia New Zealand Policing Advisory Agency and National Institute of Forensic Science

2017: Winner of ALGA Outstanding Leadership by a Woman in the Contaminated Land & Groundwater Industry

2017: Finalist of ALGA Outstanding Individual in the Contaminated Land & Groundwater Industry

Publications

Peer-reviewed journal articles:

Kerry, G.L., Ross, K.E., Wright, J.L. and Walker, G.S., 2022. A Review of Methods UUsed to Detect Methamphetamine from Indoor Air and Textiles in Confined Spaces. Toxics, 10, 710.

Kuhn, E.J., Walker, G.S., Whiley, H. Wright, J. and Ross, K.E., 2021. Overview of Current Practices in the Methamphetamine Testing and Decontamination Industry: An Australian Case Study. International Journal of Environmental Research and Public Health 18, 8917.

Wright, J., B. Symons, J. Angell, K. E. Ross and S. Walker, 2021. Current practices underestimate environmental exposures to methamphetamine: inhalation exposures are important. Journal of Exposure Science & Environmental Epidemiology 31: 45-54.

Kuhn, E.J., Walker, G.S., Wright, J., Whiley, H. and Ross, K.E., 2021. Public health challenges facing Environmental Health Officers during COVID-19: methamphetamine contamination of properties. Australian and New Zealand Journal of Public Health, 45: 9-12.

Wright, J., M. Kenneally, K. Ross and S. Walker, 2020. Environmental Methamphetamine Exposures and Health Effects in 25 Case Studies. Toxics 8 (3): 61.

Wright, J., G. S. Walker and K. E. Ross, 2019. Contamination of Homes with Methamphetamine: Is Wipe Sampling Adequate to Determine Risk? International Journal of Environmental Research and Public Health 16 (19): 3568.

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Appendix B Thresholds for non-regulated waste in Queensland

Reclaimed Plastics in Road Infrastructure: Technical Review
Ref: AT/21/RPR001-D

The following table is extracted from the EP Regulation, Schedule 9, Part 3, Division 2, Table 2 and are thresholds, below which solid and liquid materials are not considered to be regulated waste in Queensland.

Table: Non-regulated waste thresholds

Column 1 Substance		Column 2 Solid waste threshold (mg/kg)	Column 3 Liquid waste threshold (µg/L)
1	aldrin and dieldrin (total)	10	6
2	antimony	9	60
3	arsenic	300	200
4	barium	4,500	40,000
5	benzene	5	20
6	benzo(a)pyrene	3	0.2
7	beryllium	90	1,200
8	boron	20,000	3,700
9	cadmium	90	2
10	carbon tetrachloride	2	60
11	chlorobenzene	84	6,000
12	chloroform	1	4
13	chromium (hexavalent)	300	10
14	copper	220	14
15	cresol (total)	4,000	3,000
16	cyanide	240	70
17	dichlorobenzene (1,2-dichlorobenzene)	540	30,000
18	dichlorobenzene (1,4-dichlorobenzene)	8	800
19	dichloroethane (1,2-dichloroethane)	1	60
20	dichloroethylene (1,1-dichloroethylene)	69	500
21	dichloromethane (methylene chloride)	105	220
22	dichlorophenoxyacetic acid (2,4-dichlorophenoxyacetic acid)	210	600
23	dieldrin and aldrin (total)	10	6
24	dinitrotoluene (2,4-dinitrotoluene)	5	5
25	ethylbenzene	17	6,000
26	fluoride	930	30,000
27	lead	300	34
28	mercury	80	6
29	methyl ethyl ketone	8,100	11,200
30	molybdenum	117	1,000
31	nickel	1,200	110
32	nitrobenzene	15	3
33	organochlorine pesticides (total)	50	0.00011
34	organophosphate pesticides (total)	250	0.035
35	per- and poly-fluoroalkyl substances (PFAS)	0	0
36	persistent organic pollutant (other)	50	0
37	petroleum hydrocarbons (C6 to C9)	950	-
38	petroleum hydrocarbons (C10 to C36)	5,300	-
39	petroleum hydrocarbons (total)	6,000	
40	phenols (total)	40,000	11,600
41	polychlorinated biphenyls (PCBs)	2	0.00074
42	polycyclic aromatic hydrocarbons (PAHs) (total)	300	0.2
43	selenium	700	110
44	styrene (vinyl benzene)	1,800	600
45	silver	117	1
46	tetrachloroethane (1,1,1,2-tetrachloroethane)	6	11
47	tetrachloroethane (1,1,2,2-tetrachloroethane)	6	2
48	tetrachloroethylene	24	82
49	trichloroethane (1,1,1-trichloroethane)	2,430	16,000
50	trichloroethane (1,1,2-trichloroethane)	0.45	0.82

	Column 1 Substance	Column 2 Solid waste threshold (mg/kg)	Column 3 Liquid waste threshold (µg/L)
51	trichloroethylene	1	6
52	trichlorophenol (2,4,5-trichlorophenol)	1,890	2,400
53	trichlorophenol (2,4,6-trichlorophenol)	19	200
54	toluene	1,470	16,000
55	vanadium	117	172
56	vinyl chloride	0.18	6
57	xylenes (total)	174	12,000
58	zinc	400	30

It is noted that this table includes a threshold for PFAS that is 0 mg/kg. This is not a meaningful threshold as it is not possible to measure 0 mg/kg as all analytical methods have a laboratory limit or reporting (LOR). In practice this threshold would mean no detectable PFAS above the analytical LOR.

Appendix C Guidelines relevant to leaching

When evaluating the potential for chemicals that may be additives or contaminants in recycled plastics, where recycled plastic is added to asphalt or bitumen including bitumen seals, the potential for leaching of these chemicals into the environment requires consideration.

The process being evaluated is the movement of chemicals from the asphalt or bitumen, at any time throughout the lifecycle of the material, from a solid to liquid phase (as soil water). Where there is sufficient water present, from rainfall or other sources (such as water used for dust suppression or irrigation), chemicals may move from the solid materials into the water and be present in surface water runoff or infiltration water that may migrate to groundwater.

Leaching in an environment is complex and will depend on (DER 2015):

- the chemical composition and physical properties of the solid material
- chemical conditions in the contacting aqueous solution including its pH, chemical composition, and oxidation-reduction potential.

The following figure shows some of physical and chemical factors that influence the magnitude and rate of leaching.

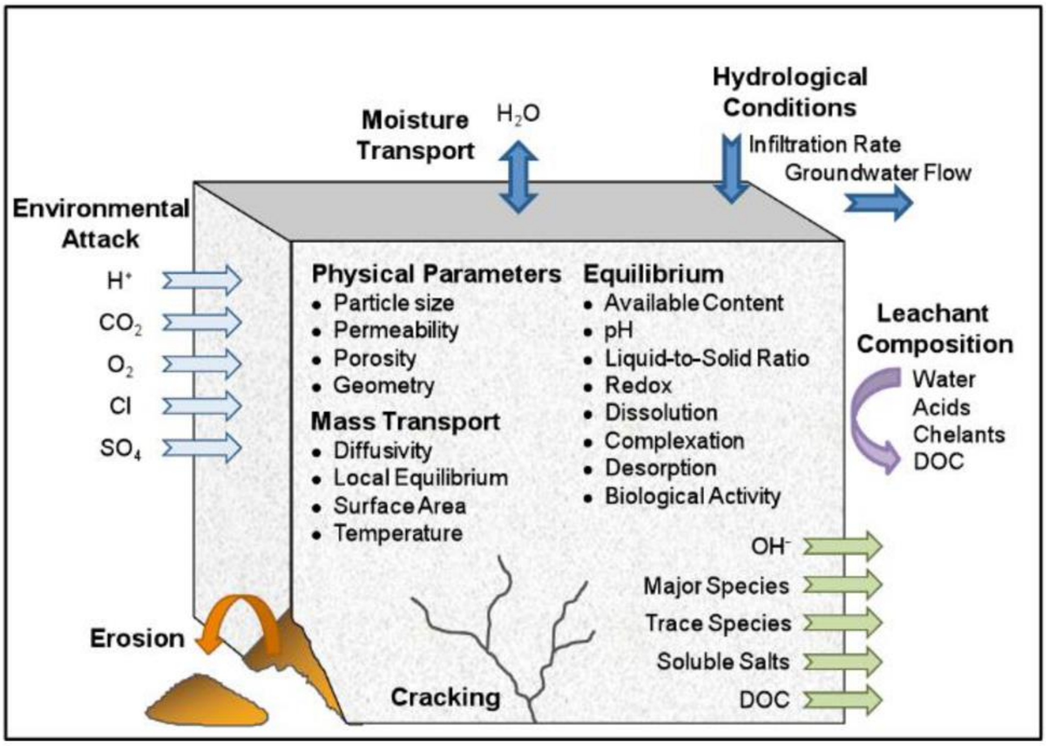

Figure: internal and external factors that influence the extent and rate of leaching of a chemical from solid into a contacting aqueous solution (DER 2015)

There are no human health or environmental values specifically relevant to the roadway, however the adjacent areas would be expected to have variable environmental values depending in the location of the roadway. More sensitive areas are those that include significant environmental waterways, or there are surface water and/or groundwater resources that are used for drinking water.

While it may be possible to develop separate guidelines for different areas (urban vs rural vs sensitive areas), where plastic modified asphalt or bitumen is removed and is intended for recycling or re-use, unless the material is tracked in some manner, it is not possible to rule out future use of such materials in roadways that are located in more sensitive environments.

Hence it is relevant to adopt guidelines for the material that are protective of all potential risks, regardless of the location of the roadway where the material may be used (at any point in the life of the material).

To assess leaching potential of materials, the laboratory test used is a leach test with the Australian standard leaching procedure (ASLP) test used to best simulate water at environmental pH. The ASLP test utilises solids where the particle size is < 2.4 mm. Deionised/reagent water is added where the liquid/solid (L/S) ratio is 20:1 (so for 100 g solid, 2000 g (or mL) if water is added) and the mixture is mixed (rotary agitator) for 18 +/- 2 hours (at 30 +/- 2 rotations per minute and 22 +/- 5 °C. The leachate is then analysed. The results that are obtained from this method are commonly assumed to represent the concentration that may leach from a solid to soil water following rainfall. The method, however has a number of limitations (DER 2015):

- Leaching is from fine particles which has a higher surface area[4] than most of the materials that would be present in asphalt or bitumen road materials as applied, during use or as removed for recycling/reuse
- The results relate to a limited pH (which is assumed to be representative of environmental conditions) and the variability in conditions is not addressed
- There is no assessment of how leaching may change where the L/S ratios changes
- The test does not provide any information on the rate of release of contaminants from the solid. It is commonly assumed that the amount leached in the test would leach every time it rains, however it is more likely that the leachate result reflects the total mass that may be leached over a much longer period of time (unknown period of time). Mass loss from leaching is not considered.

The above indicates that the results of the ASLP test is only an indicative measure of potential leaching from materials, and is expected to provide a conservative measure of what may occur after rainfall occurs.

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[4] The higher the surface area of the particulates in the test, the greater contact area with leach fluid and the higher the leaching

To determine if the leachable concentrations are significant, it is overly conservative to simply adopt water guidelines that are protective of the most sensitive endpoints for human health (i.e. drinking water) and aquatic environments (default guideline values for fresh and marine water).

These guidelines are relevant as the values that require protection at the receiving water body, being groundwater and/or surface water. For chemicals to leach and migrate to these water bodies there has to be sufficient rainfall to result in runoff or infiltration to groundwater. To move from a road corridor where the materials would be used or stockpiled to a receiving water environment, some level of dilution would need to occur.

Methods are available for the quantification of dilution factors relevant to infiltration to groundwater and also surface water runoff. These methods are site specific and are difficult to apply generally for asphalt/bitumen materials that may be used in a wide range of areas. The extent of road pavement where plastic modified asphalt/bitumen may be used is also unknown.

The most commonly used default dilution factor that is applied when undertaking generic assessment of leaching is 20 fold. This comes from the USEPA Soil Screening Guidance (USEPA 1996), where they recognised that the concentration of a chemical in soil leachate is not the same as the concentration of the chemical that will reach a receptor, as processes will occur in the environment that will decrease the concentration of the chemical.

Based on a review of data from a range of uncontrolled sites with varying source sizes, soil types and depths to groundwater, USEPA (1996) determined a default DF of 20 for a source area of 0.5 acres in size. An uncontrolled site is a site where the chemical is present in soil without any capping of any type and there may be environmental values relevant to the groundwater directly beneath the impacted material (which is not relevant for road corridors[5]). The selection of the default of 20 appears to be based on USEPA's professional judgement rather than a statistical measure of the available data. The default DF of 20 has been adopted by the ASC NEPM in the derivation of soil ecological guidelines (Schedule B5C). The ASC NEPM remains the overarching guideline in Australia for the assessment of contaminants. Hence, a DF of 20 times is considered appropriate for use in the HHERA which has been undertaken in accordance with the ASC NEPM.

Although the DF of 20 is noted to be derived based on the migration of chemicals to groundwater, it is also considered protective of direct run-off to surface water.

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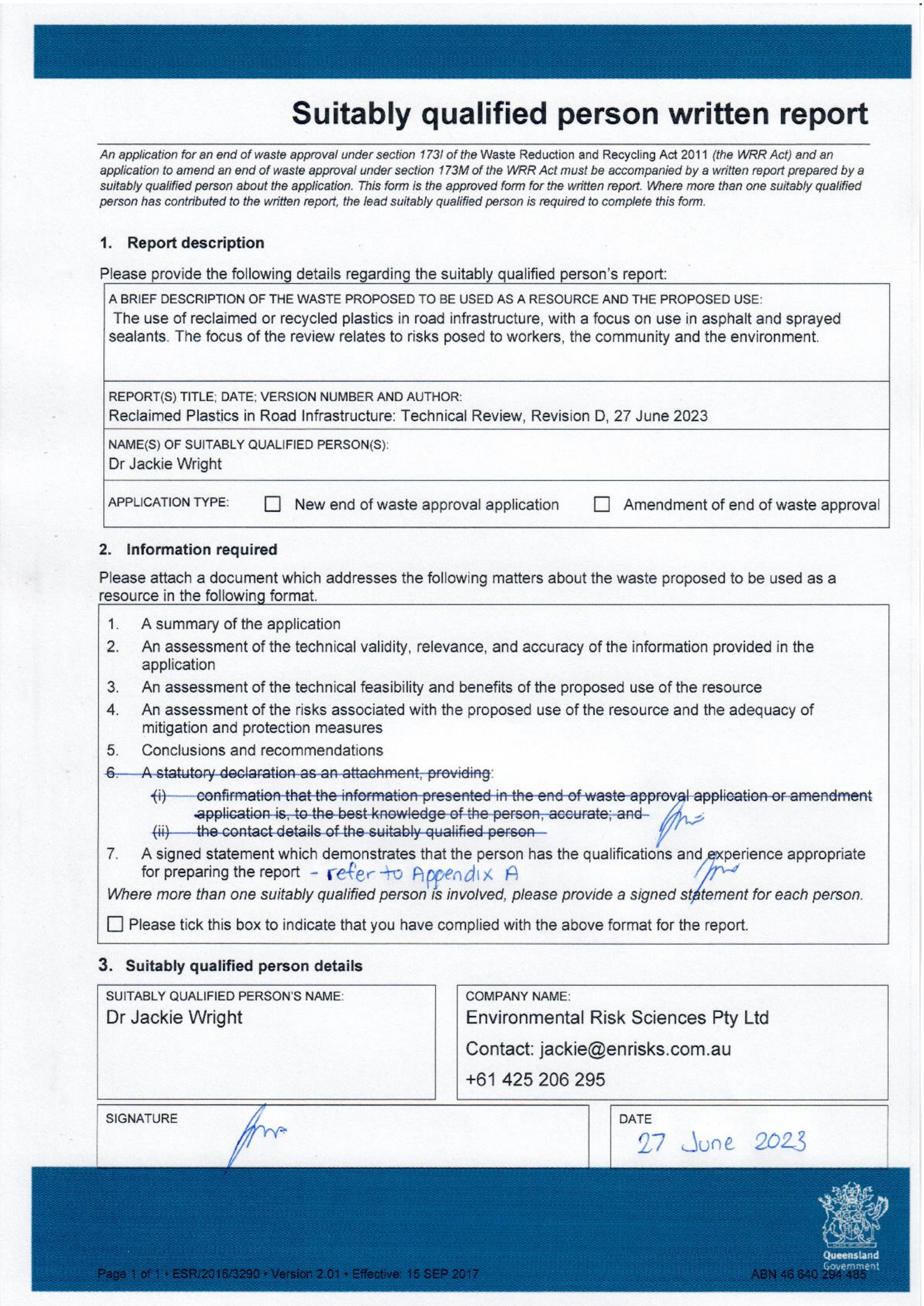
[5] Road corridors would not have groundwater that is extracted from directly beneath the roadway and used for any purpose. Groundwater beneath the road corridor would have to migrate and mix downgradient to a point of extraction or surface water body (where discharge may occur). Where mixing downgradient is considered then a dilution factor would be higher than 20 fold.

Appendix D SQP Report



Suitably qualified person written report

An application for an end of waste approval under section 173I of the Waste Reduction and Recycling Act 2011 *(the WRR Act) and an application to amend an end of waste approval under section 173M of the WRR Act must be accompanied by a written report prepared by a suitably qualified person about the application. This form is the approved form for the written report. Where more than one suitably qualified person has contributed to the written report, the lead suitably qualified person is required to complete this form.*

1. Report description

Please provide the following details regarding the suitably qualified person's report:

A BRIEF DESCRIPTION OF THE WASTE PROPOSED TO BE USED AS A RESOURCE AND THE PROPOSED USE:
The use of reclaimed or recycled plastics in road infrastructure, with a focus on use in asphalt and sprayed sealants. The focus of the review relates to risks posed to workers, the community and the environment.

REPORT(S) TITLE; DATE; VERSION NUMBER AND AUTHOR:
Reclaimed Plastics in Road Infrastructure: Technical Review, Revision D, 27 June 2023

NAME(S) OF SUITABLY QUALIFIED PERSON(S):
Dr Jackie Wright

APPLICATION TYPE: ☐ New end of waste approval application ☐ Amendment of end of waste approval

2. Information required

Please attach a document which addresses the following matters about the waste proposed to be used as a resource in the following format.

1. A summary of the application
2. An assessment of the technical validity, relevance, and accuracy of the information provided in the application
3. An assessment of the technical feasibility and benefits of the proposed use of the resource
4. An assessment of the risks associated with the proposed use of the resource and the adequacy of mitigation and protection measures
5. Conclusions and recommendations
6. ~~A statutory declaration as an attachment, providing~~:
   - ~~(i) confirmation that the information presented in the end of waste approval application or amendment application is, to the best knowledge of the person, accurate; and~~
   - ~~(ii) the contact details of the suitably qualified person~~
7. A signed statement which demonstrates that the person has the qualifications and experience appropriate for preparing the report - refer to Appendix A

Where more than one suitably qualified person is involved, please provide a signed statement for each person.

☐ Please tick this box to indicate that you have complied with the above format for the report.

3. Suitably qualified person details

SUITABLY QUALIFIED PERSON'S NAME:
Dr Jackie Wright

COMPANY NAME:
Environmental Risk Sciences Pty Ltd
Contact: jackie@enrisks.com.au
+61 425 206 295

SIGNATURE

DATE
27 June 2023

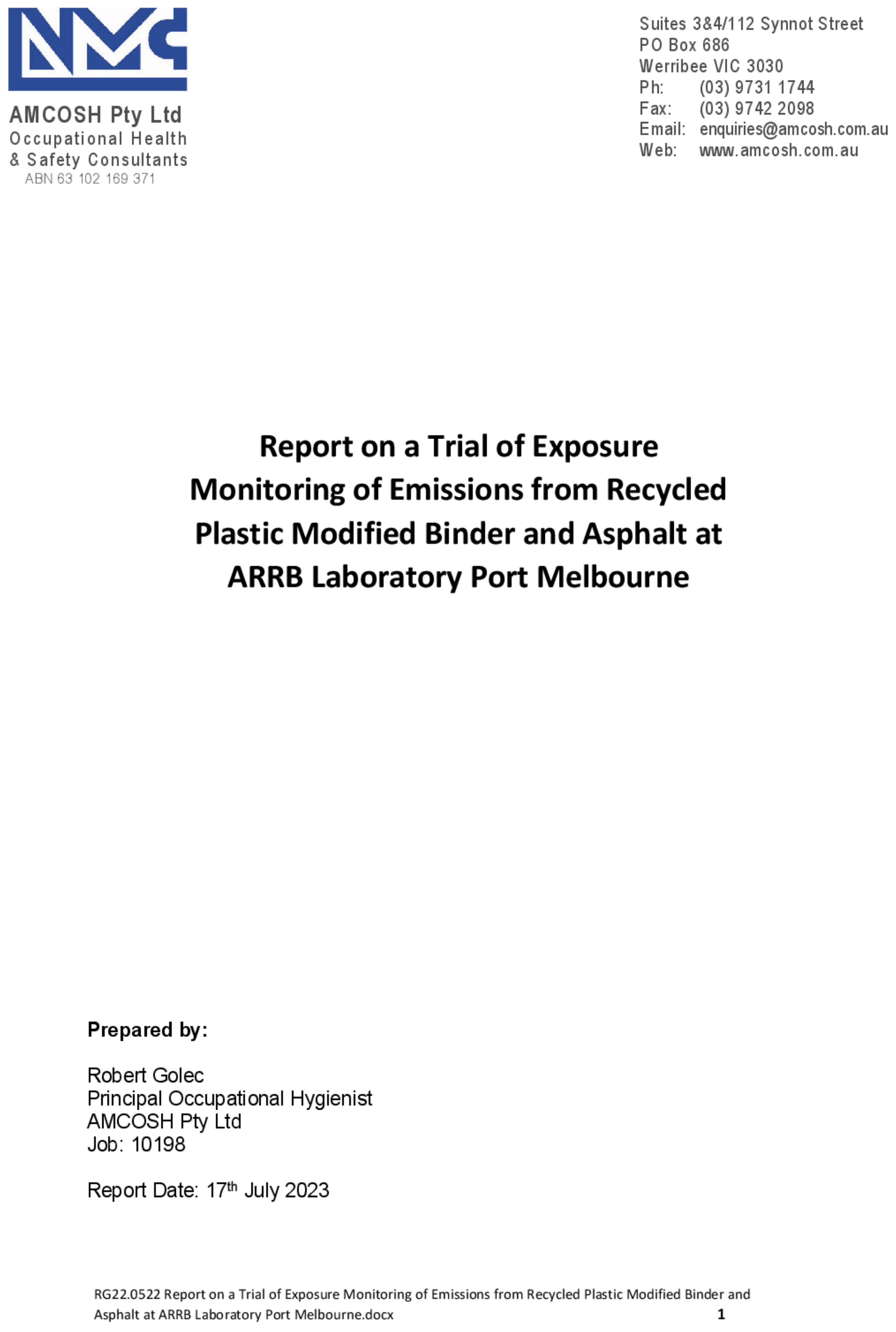
Page 1 of 1 • ESR/2016/3290 • Version 2.01 • Effective: 15 SEP 2017

Queensland Government

ABN 46 640 294 485

Appendix B AMCOSH Reports

B.1 Laboratory Fumes and Emissions



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Report on a Trial of Exposure Monitoring of Emissions from Recycled Plastic Modified Binder and Asphalt at ARRB Laboratory Port Melbourne

Prepared by:

Robert Golec
Principal Occupational Hygienist
AMCOSH Pty Ltd
Job: 10198

Report Date: 17th July 2023

Contents

Introduction

As part of an ARRB-lead project on a laboratory-based fume emissions testing, AMCOSH Pty Ltd undertook personal and static monitoring to assess the potential exposures to airborne contaminants during the handling of bitumen to which various waste plastics had been added.

The project was undertaken in two parts – Part A was undertaken using C320 grade bitumen as the base bitumen material and Part B was undertaken using C170 bitumen. The Part A monitoring using C320 bitumen took place on 30th and 31st March and 1st April 2022 at the ARRB Facilities at 80a Turner St, Port Melbourne. The following activities were monitored during the three days of trials:

Date	Location	Product
30 March 2022	Asphalt Laboratory	C320 Asphalt mixing and compacting
	Main Laboratory	C320 Bitumen Blending
	Asphalt Laboratory	C320 + 5% HDPE/PP (Dry Method) Asphalt mixing and compacting
	Main Laboratory	C320 + 6% HDPE/PP Blending
31 March 2022	Asphalt Laboratory	C320 + 6% SBS (Wet Method) Asphalt mixing and compacting
	Asphalt Laboratory	C320 + 6% EVA (Wet Method) Asphalt mixing and compacting
	Main Laboratory	C320 + 6% EVA Blending
1 April 2022	Asphalt Laboratory	C320 + 6% HDPE/PP (Wet Method) Asphalt mixing and compacting
	Main Laboratory	C320 + 6% SBS Blending

The purpose of the monitoring was to assess whether there were potential exposures to the laboratory staff undertaking testing of bitumen blends to volatile organic compounds (VOCs)/petroleum hydrocarbons, Bitumen Fumes (BF) (also referred to as Coal Tar Pitch Volatiles), Total Suspended Particulates (TSP), Polycyclic Aromatic Compounds (PAHs) and Aldehydes. For the sake of consistency, to reduce any variables related to work practices, the same staff members were monitored throughout the trials of the different blends.

Methodology

Monitoring for VOCs, PAHs, BF, TSP and Aldehydes was undertaken simultaneously on the laboratory staff members during testing of the various blends. Additionally, static sampling was undertaken in the Asphalt Laboratory and Main Laboratory areas. The sampling pumps were connected by Tygon® tubing to the appropriate sampling media placed in the breathing zone of the operator (the breathing zone is defined as a hemisphere of 300 mm radius extending to the front of the face, measured from the midpoint of an imaginary line joining the ears - see Figure 2 below).

Figure 1 – Laboratory staff members wearing backpack with sampling pumps and devices during asphalt testing.

Figure 2 – Breathing zone (taken from SafeWork Australia https://www.safeworkaustralia.gov.au/assessing-risk)

Static samplers attached to tripods were placed adjacent to the areas where the handling activities of the mixes took place. For the Asphalt Laboratory, the static samples were located next to the ovens where the asphalt mixes were heated, next to the pug mixer during mixing, next to the compaction equipment during compaction and next to the bench during coning and quartering of the mixes. For the Main Laboratory, the static equipment was located at the face of the fume cabinet where the bitumen blends were heated and sampled.

The sampling pump and sampling device flowrates were set to those recommended in the methods and measured and recorded immediately prior to the commencement of monitoring and re-measured immediately after sampling was completed. The following methods were used for the sampling of airborne contaminants for each monitoring trial of the various mixes. The individual laboratory certificates of analysis are included in Appendix 1 of this report.

Volatile Organic Compounds (VOCs)

Sampling for VOCs in the breathing zone of the operators was undertaken by drawing air through activated coconut shell charcoal tubes (SKC Part Number 226-01) at a flowrate of approximately 0.1 litres per minute in accordance with NIOSH Method 1500 (Hydrocarbons, BP 36°-216 °C), NIOSH Method 1501 (Hydrocarbons, Aromatic) and Australian Standard AS 2986.1-2003: Workplace air quality - Sampling and analysis of volatile organic compounds by solvent desorption/gas chromatography - Pumped sampling method.

Following sampling, the samples were refrigerated until they were dispatched for laboratory analysis. All VOC samples were analysed by TestSafe Australia (the chemical analysis branch of Safework NSW) by the method of solvent desorption with carbon disulphide and analysis by gas chromatography/mass spectrometry by method WCA.2.07 Analysis of Volatile Organic Compounds in Workplace Air by Gas Chromatography/Mass Spectrometry. TestSafe Australia is NATA accredited for this method (Accreditation No 3726) in compliance with ISO/IEC Standard 17025-Testing. The analytical method has a limit of reporting (LOR - the lowest amount of VOC which can be reported with 95% confidence) of 5 micrograms (µg) per sampling tube for aromatic and aliphatic hydrocarbons.

Polycyclic Aromatic Hydrocarbons (PAHs)

Sampling of PAHs in the breathing zone of the two operators was undertaken by drawing air at approximately 2.0 to 2.5 litres per minute through a pre-weighed PTFE filter to collect particulate matter with an XAD-2 solid sorbent sampling tube connected at the rear of the filter cassette to collect volatile (gaseous) PAHs in accordance with NIOSH Method 5800 Polycyclic Aromatic Compounds.

Following sampling, the samples were refrigerated until they were dispatched for laboratory analysis. The samples were analysed for PAHs by TestSafe Australia (the chemical analysis branch of Safework NSW) by the method of solvent desorption and analysis by gas chromatography/mass spectrometry by method WCA 178 Analysis of Polycyclic Aromatic Hydrocarbons in Air by Gas Chromatography/Triple Quadrupole Mass Spectrometer. The limit of reporting (LOR) for the PAH analysis was 0.1 µg per filter/tube. One tube was used per monitoring session.

Aldehydes

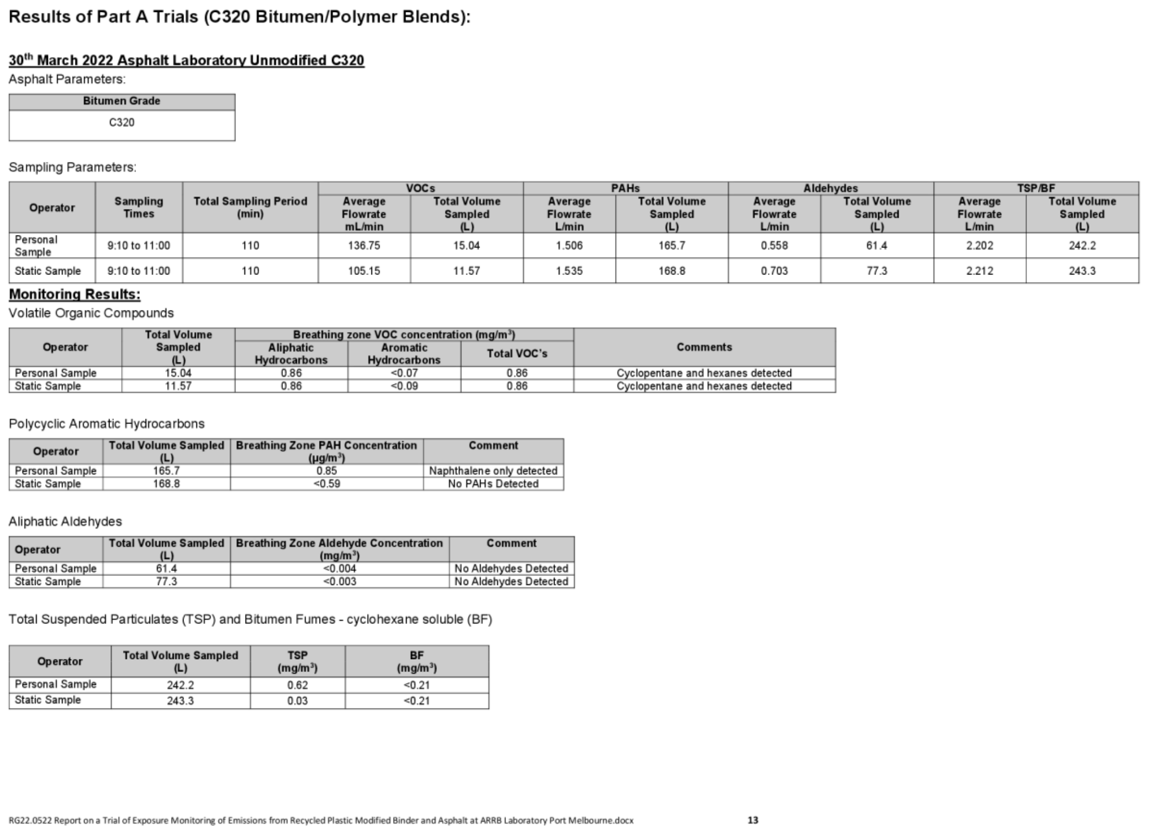
Sampling for aldehydes was undertaken by drawing air at approximately 0.5 to 1.0 litres per minute through a 2,4-dinitropheylhydrazone (DNPH) treated silica gel tubes to collect and derivatise aliphatic aldehydes in accordance with NIOSH Method 2018 Aliphatic Aldehydes in Air.

Following sampling, the samples were refrigerated until they were dispatched for laboratory analysis. The samples were analysed by TestSafe Australia by the method of solvent extraction with acetonitrile and High-Performance Liquid Chromatography (HPLC). The LOR of aldehydes was 0.25 µg per tube. One tube was used per monitoring session.

Total Suspended Particulates (TSP) and Bitumen Fume (BF)

Sampling for TSP and BF was undertaken in the breathing zone by drawing air at approximately 2.0 to 2.5 litres per minute through a pre-weighed PTFE filter in accordance with NIOSH Method 5040.

Following sampling, the samples were refrigerated until they were dispatched for laboratory analysis. All TSP/BF samples were analysed by SIMTARS (Safety in Mines Testing and Research Station) Queensland by gravimetry and solvent extraction using cyclohexane. The LOR for TSP is 0.01 mg and for BF is 0.05 mg per filter. One filter was used per monitoring session.



Results of Part A Trials (C320 Bitumen/Polymer Blends):

30th March 2022 Asphalt Laboratory Unmodified C320

Asphalt Parameters:

Bitumen Grade
C320

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	9:10 to 11:00	110	136.75	15.04	1.506	165.7	0.558	61.4	2.202	242.2
Static Sample	9:10 to 11:00	110	105.15	11.57	1.535	168.8	0.703	77.3	2.212	243.3

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	15.04	0.86	<0.07	0.86	Cyclopentane and hexanes detected
Static Sample	11.57	0.86	<0.09	0.86	Cyclopentane and hexanes detected

Polycyclic Aromatic Hydrocarbons

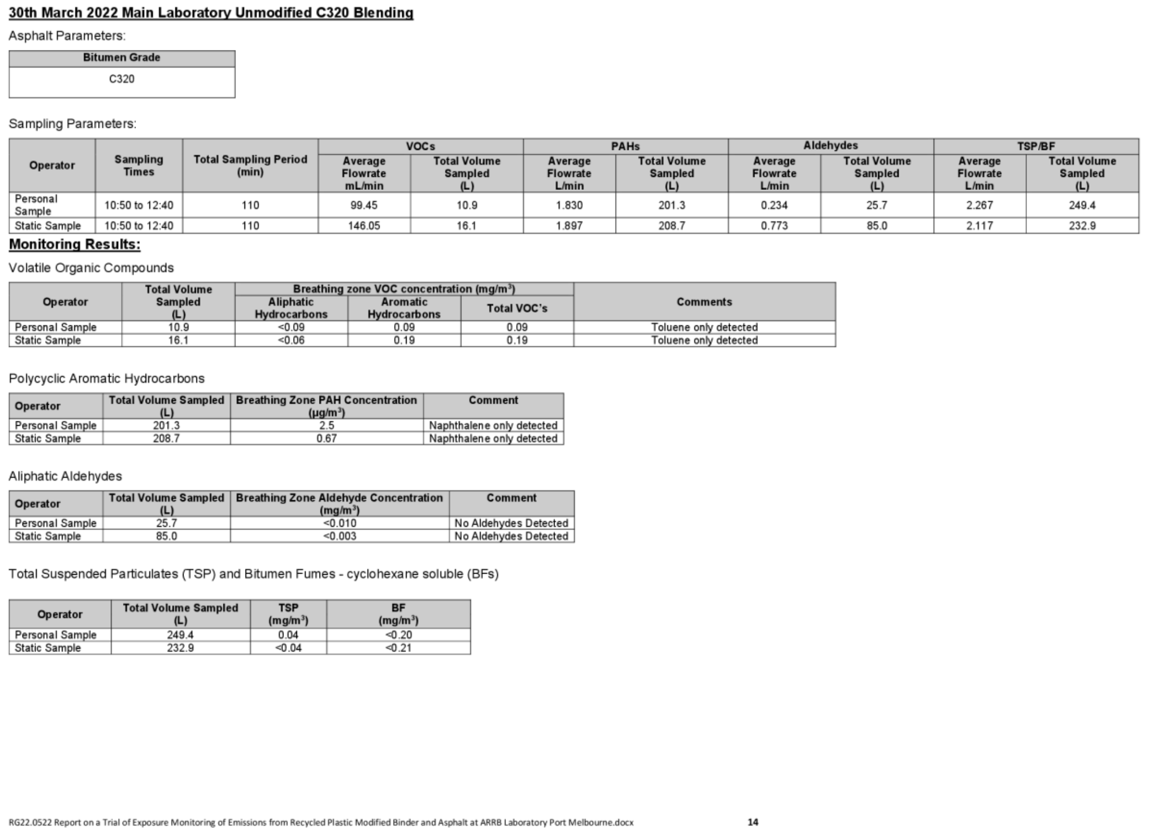
Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	165.7	0.85	Naphthalene only detected
Static Sample	168.8	<0.59	No PAHs Detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	61.4	<0.004	No Aldehydes Detected
Static Sample	77.3	<0.003	No Aldehydes Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	242.2	0.62	<0.21
Static Sample	243.3	0.03	<0.21



30th March 2022 Main Laboratory Unmodified C320 Blending

Asphalt Parameters:

Bitumen Grade
C320

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	10:50 to 12:40	110	99.45	10.9	1.830	201.3	0.234	25.7	2.267	249.4
Static Sample	10:50 to 12:40	110	146.05	16.1	1.897	208.7	0.773	85.0	2.117	232.9

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	10.9	<0.09	0.09	0.09	Toluene only detected
Static Sample	16.1	<0.06	0.19	0.19	Toluene only detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	201.3	2.5	Naphthalene only detected
Static Sample	208.7	0.67	Naphthalene only detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	25.7	<0.010	No Aldehydes Detected
Static Sample	85.0	<0.003	No Aldehydes Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	249.4	0.04	<0.20
Static Sample	232.9	<0.04	<0.21

30th March 2022 Asphalt Laboratory C320 + 5% HDPE/PP (Dry Method)

Asphalt Parameters:

Bitumen Grade
C320

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	11:47 to 13:43	116	141.8	16.4	1.490	172.8	0.534	61.9	2.211	256.5
Static Sample	11:47 to 13:43	116	107.9	12.5	1.530	177.4	0.782	90.7	2.229	258.6

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	16.4	<0.06	0.12	0.12	Toluene only detected
Static Sample	12.5	<0.08	0.16	0.16	Toluene only detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	172.8	0.93	Naphthalene only detected
Static Sample	177.4	<0.56	No PAHs Detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	61.9	0.008	Formaldehyde only Detected
Static Sample	90.7	<0.002	No Aldehydes Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	256.5	0.55	<0.19
Static Sample	258.6	0.08	<0.19

30th March 2022 Main Laboratory C320 + 6% HDPE/PP Blending

Asphalt Parameters:

Bitumen Grade
C320

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	14:32 to 16:29	117	138.4	16.2	1.816	212.5	0.763	89.2	2.260	264.4
Static Sample	14:32 to 16:29	117	97.4	11.4	1.917	224.3	0.749	87.6	2.116	247.6

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	16.2	<0.06	<0.06	<0.06	No VOCs Detected
Static Sample	11.4	<0.09	<0.09	<0.09	No VOCs Detected

Polycyclic Aromatic Hydrocarbons

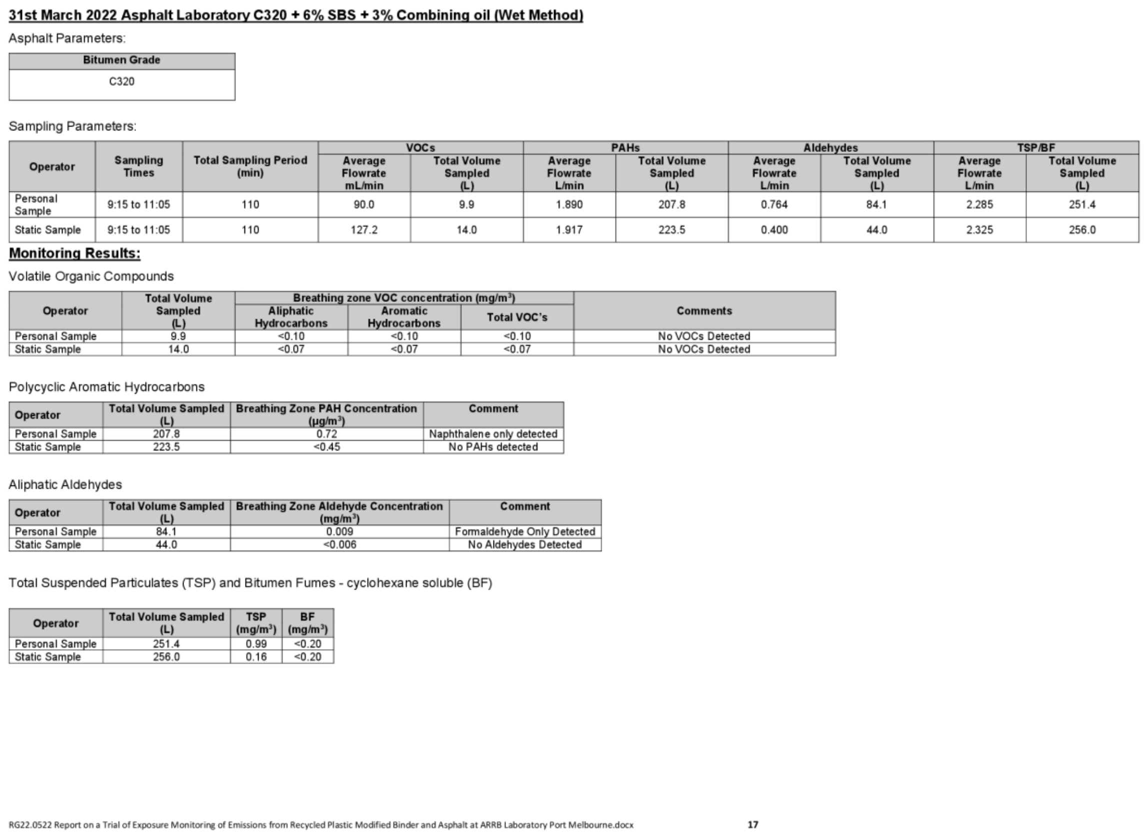
Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	212.5	2.4	Naphthalene only detected
Static Sample	224.3	0.53	Naphthalene only detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	89.2	<0.003	No Aldehydes Detected
Static Sample	87.6	0.003	Formaldehyde Only Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	264.4	0.04	<0.19
Static Sample	247.6	<0.04	<0.20



31st March 2022 Asphalt Laboratory C320 + 6% SBS + 3% Combining oil (Wet Method)

Asphalt Parameters:

Bitumen Grade
C320

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	9:15 to 11:05	110	90.0	9.9	1.890	207.8	0.764	84.1	2.285	251.4
Static Sample	9:15 to 11:05	110	127.2	14.0	1.917	223.5	0.400	44.0	2.325	256.0

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m^3)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	9.9	<0.10	<0.10	<0.10	No VOCs Detected
Static Sample	14.0	<0.07	<0.07	<0.07	No VOCs Detected

Polycyclic Aromatic Hydrocarbons

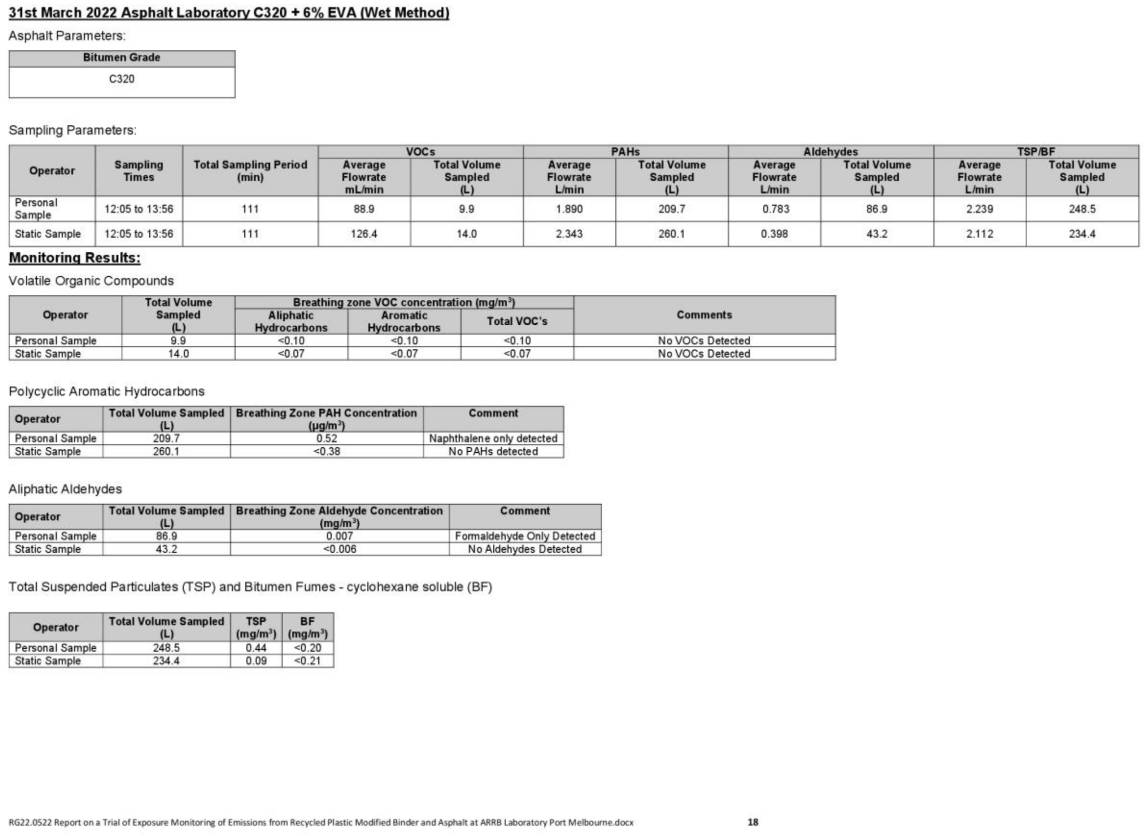
Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m^3)	Comment
Personal Sample	207.8	0.72	Naphthalene only detected
Static Sample	223.5	<0.45	No PAHs detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m^3)	Comment
Personal Sample	84.1	0.009	Formaldehyde Only Detected
Static Sample	44.0	<0.006	No Aldehydes Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

Operator	Total Volume Sampled (L)	TSP (mg/m^3)	BF (mg/m^3)
Personal Sample	251.4	0.99	<0.20
Static Sample	256.0	0.16	<0.20



31st March 2022 Asphalt Laboratory C320 + 6% EVA (Wet Method)

Asphalt Parameters:

Bitumen Grade
C320

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	12:05 to 13:56	111	88.9	9.9	1.890	209.7	0.783	86.9	2.239	248.5
Static Sample	12:05 to 13:56	111	126.4	14.0	2.343	260.1	0.398	43.2	2.112	234.4

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m^3)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	9.9	<0.10	<0.10	<0.10	No VOCs Detected
Static Sample	14.0	<0.07	<0.07	<0.07	No VOCs Detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m^3)	Comment
Personal Sample	209.7	0.52	Naphthalene only detected
Static Sample	260.1	<0.38	No PAHs detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m^3)	Comment
Personal Sample	86.9	0.007	Formaldehyde Only Detected
Static Sample	43.2	<0.006	No Aldehydes Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

Operator	Total Volume Sampled (L)	TSP (mg/m^3)	BF (mg/m^3)
Personal Sample	248.5	0.44	<0.20
Static Sample	234.4	0.09	<0.21

31st March 2022 Main Laboratory C320 + 6% EVA Blending

Asphalt Parameters:

Bitumen Grade
C320

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	11:20 to 13:05	105	110.4	11.6	2.270	238.4	0.741	77.8	2.127	223.3
Static Sample	11:20 to 13:05	105	145.0	15.2	1.565	164.3	0.764	80.2	2.386	250.2

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	11.6	<0.09	<0.09	<0.09	No VOCs Detected
Static Sample	15.2	<0.07	<0.07	<0.07	No VOCs Detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	238.4	<0.42	No PAHs Detected
Static Sample	164.3	<0.61	No PAHs Detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	77.8	0.007	Formaldehyde Only Detected
Static Sample	80.2	0.004	Formaldehyde Only Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	223.3	0.04	<0.22
Static Sample	250.2	<0.04	<0.20

1st April 2022 Asphalt Laboratory C320 + 6% HDPE/PP (Wet Method)

Asphalt Parameters:

Bitumen Grade
C320

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	09:00 to 11:00	120	106.3	12.8	2.065	247.7	0.765	91.8	2.269	272.3
Static Sample	09:00 to 11:00	120	115.4	13.8	2.312	277.4	0.754	90.5	2.108	252.9

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	12.8	<0.07	<0.07	<0.07	No VOCs Detected
Static Sample	13.8	<0.07	<0.07	<0.07	No VOCs Detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	247.7	0.73	Naphthalene only detected
Static Sample	277.4	0.61	Naphthalene only detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	91.8	0.005	Formaldehyde Only Detected
Static Sample	90.5	0.003	Formaldehyde Only Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	272.3	0.26	<0.18
Static Sample	252.9	0.04	<0.20

1st April 2022 Main Laboratory C320 + 6% SBS + 3% Combining oil Blending

Asphalt Parameters:

Bitumen Grade
C320

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	10:22 to 12:07	105	143.0	15.0	2.471	259.4	0.719	75.5	2.986	313.5
Static Sample	10:22 to 12:07	105	112.5	11.8	2.225	233.6	0.431	45.2	2.158	226.6

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m^3)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	15.0	<0.07	<0.07	<0.07	No VOCs Detected
Static Sample	11.8	<0.08	<0.08	<0.08	No VOCs Detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m^3)	Comment
Personal Sample	259.4	2.1	Naphthalene Only Detected
Static Sample	233.6	0.60	Naphthalene Only Detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m^3)	Comment
Personal Sample	75.5	0.004	Formaldehyde Only Detected
Static Sample	45.2	<0.006	No Aldehydes Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

Operator	Total Volume Sampled (L)	TSP (mg/m^3)	BF (mg/m^3)
Personal Sample	313.5	0.06	<0.16
Static Sample	226.6	<0.04	<0.22

Discussion of Results

VOC Result Comparison

Asphalt Laboratory Results

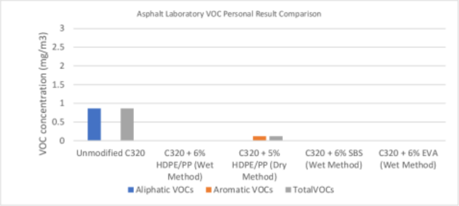
Sample	Unmodified C320			C320 + 6% HDPE/PP (Wet Method)			C320 + 5% HDPE/PP (Dry Method)			C320 + 6% SBS (Wet Method)			C320 + 6% EVA (Wet Method)		
	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)
Asphalt Lab Personal Sample	0.86*	<0.07	0.86	<0.07	<0.07	<0.07	<0.06	0.12+	0.12	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Asphalt Lab Static Sample	0.86*	<0.07	0.86	<0.07	<0.07	<0.07	<0.08	0.16+	0.16	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07

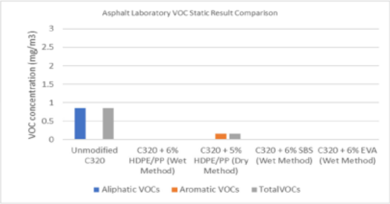
* Cyclopentane and hexanes (excluding n-hexanes) only detected
+ Toluene only detected

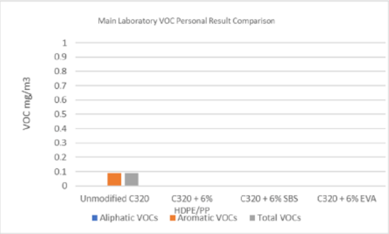
Main Laboratory Results

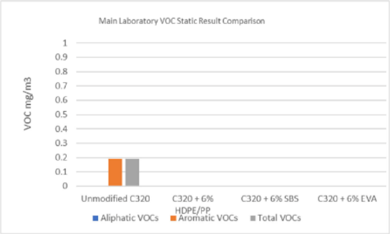
Sample	Unmodified C320			C320 + 6% HDPE/PP			C320 + 6% SBS			C320 + 6% EVA		
	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)
Main Lab Personal Sample - Blending	<0.09	0.09+	0.09	<0.06	<0.06	<0.06	<0.07	<0.07	<0.07	<0.09	<0.09	<0.09
Main Lab Static Sample - Blending	<0.06	0.19+	0.19	<0.09	<0.09	<0.09	<0.08	<0.08	<0.08	<0.07	<0.07	<0.07

+ Toluene only detected






Main Laboratory VOC Personal Result Comparison
VOC mg/m3
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Unmodified C320
C320 + 6% HDPE/PP
C320 + 6% SBS
C320 + 6% EVA
Aliphatic VOCs
Aromatic VOCs
Total VOCs


Main Laboratory VOC Static Result Comparison
VOC mg/m3
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Unmodified C320
C320 + 6% HDPE/PP
C320 + 6% SBS
C320 + 6% EVA
Aliphatic VOCs
Aromatic VOCs
Total VOCs

Comments: VOCs can be emitted when plastics are heated through a process of thermal decomposition. Additionally, bitumen can also emit petroleum hydrocarbons when heated. The composition of the VOCs is dependent on the chemical composition of plastic and on the temperature and includes both aliphatic and aromatic hydrocarbons. SafeWork Australia sets Workplace Exposure Standards for airborne substances in the breathing zone. The following table summarises the SafeWork Australia Workplace Exposure Standards for a selection of VOCs which may be emitted during heating of a bitumen/plastic mix.

SafeWork Australia Workplace Exposure Standards for selected VOCs

Chemical	Time-weighted Average (TWA)~ Workplace Exposure Standard (mg/m^3)	Time-weighted Average (TWA) Workplace Exposure Standard (ppm)
Pentane	1770	600
Hexanes	1760	500
n-hexane	72	20
Cyclohexane	350	100
Methyl Cyclohexane	1610	400
n-heptane	1640	400
Octane	1400	300
Nonane	1050	200
Benzene	3.2	1
Toluene	191	50
Xylene	350	80
Ethylbenzene	434	100
Styrene	213	50
Cumene	125	25
Trimethylbenzene	123	25
Total VOC (as White Spirit)	790	-

~TWA = Average concentration over an 8-hour shift

The highest levels of VOC detected in the breathing zone of the Asphalt Laboratory technician was during handling of unmodified C320 at 0.86 mg/m^3, which comprised 0.17 mg/m^3 of cyclopentane, 0.52 mg/m^3 of hexanes (other than n-hexane and cyclohexane) and 0.17 mg/m^3 of cyclohexane. This represents 0.03%, 0.01% and 0.06% of the respective exposure standards and 0.09% of the combined exposure standard for all three VOCs. Toluene was the only VOC detected in the breathing zone during handling of C320 + 5% HDPE/PP (dry method) in the asphalt laboratory. The level of 0.12 mg/m^3 represents 0.06% of the toluene workplace exposure standard.

The highest personal breathing zone concentration of the person undertaking blending in the Main Laboratory was 0.09 mg/m^3 for unmodified C320. This level comprised toluene only and represents 0.05% of the toluene workplace exposure standard.

It should be noted that in all cases, the actual time-weighted average exposure over an 8-hour workday would be significantly lower than indicated by the average concentration over the sampling period, assuming that no other exposure occurs.

Conclusion: No significant amounts of VOCs were detected in any of the samples. All levels of VOCs detected during handling of the various bitumen/plastic mixes in both the Asphalt Laboratory and Main Laboratory were well below the TWA SafeWork Australia Workplace Exposure Standards for individual VOCs and total VOCs.

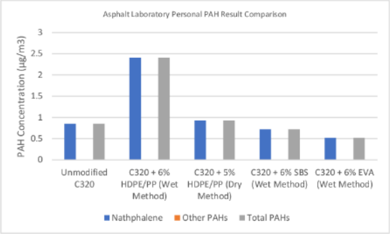
PAH Result Comparison

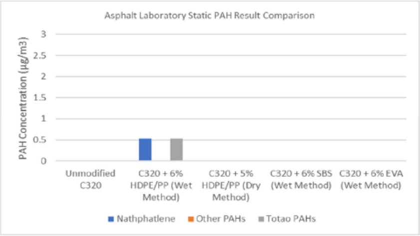
Asphalt Laboratory Results

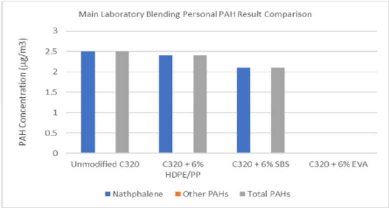
Sample	Unmodified C320			C320 + 6% HDPE/PP (Wet Method)			C320 + 5% HDPE/PP (Dry Method)			C320 + 6% SBS (Wet Method)			C320 + 6% EVA (Wet Method)		
	Naphthalene (μg/m³)	Other PAHs (μg/m³)	Total PAHs (μg/m³)	Naphthalene (μg/m³)	Other PAHs (μg/m³)	Total PAHs (μg/m³)	Naphthalene (μg/m³)	Other PAHs (μg/m³)	Total PAHs (μg/m³)	Naphthalene (μg/m³)	Other PAHs (μg/m³)	Total PAHs (μg/m³)	Naphthalene (μg/m³)	Other PAHs (μg/m³)	Total PAHs (μg/m³)
Asphalt Lab Personal Sample	0.85	<0.60	0.85	2.4	<0.47	2.4	0.93	<0.60	0.93	0.72	<0.48	0.72	0.52	<0.47	0.52
Asphalt Lab Static Sample	<0.59	<0.59	<0.59	0.53	<0.45	0.53	<0.56	<0.56	<0.56	<0.45	<0.45	<0.45	<0.38	<0.38	<0.38

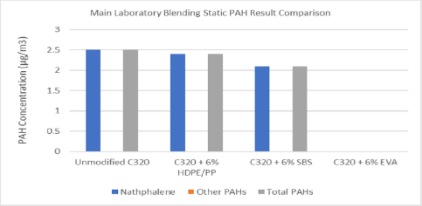
Main Laboratory Results

Sample	Unmodified C320			C320 + 6% HDPE/PP			C320 + 6% SBS			C320 + 6% EVA		
	Naphthalene (μg/m³)	Other PAHs (μg/m³)	Total PAHs (μg/m³)	Naphthalene (μg/m³)	Other PAHs (μg/m³)	Total PAHs (μg/m³)	Naphthalene (μg/m³)	Other PAHs (μg/m³)	Total PAHs (μg/m³)	Naphthalene (μg/m³)	Other PAHs (μg/m³)	Total PAHs (μg/m³)
Main Lab Personal Sample	2.5	<0.49	2.5	2.4	<0.46	2.4	2.1	<0.38	2.1	<0.42	<0.42	<0.42
Main Lab Static Sample	0.67	<0.47	0.67	0.53	<0.45	0.53	0.60	<0.42	0.60	<0.61	<0.61	<0.61









Comments: PAHs are molecules containing fused benzene ring systems. This structure includes the most basic two-ring naphthalene or four-ring pyrene and higher five-ring benzo(a)pyrene (B[a]P) and six-ring dibenzo(a,e)pyrene molecular compounds which are found in hundreds of PAH compounds. PAHs are present in crude oils and crude oil products in low concentrations. Bitumen consists of a complex mixture of organic compounds, including PAHs, which may vary in characteristics depending on the origin of the crude oil, refining process, and additives. Measurement of PAHs is undertaken by quantifying 17 PAHs identified by the US EPA as posing the greatest concern, several of which are known to be potentially carcinogenic to humans.

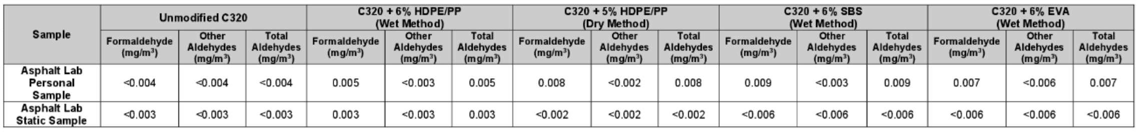
SafeWork Australia has set a workplace exposure standard for only one PAH, naphthalene – the simplest PAH - at 52 mg/m^3 (52,000 µg/m^3) as an 8-hour TWA concentration in the breathing zone. The Australian Institute of Occupational Hygienists (AIOH) recommends that a workplace exposure standard for benzo(a)pyrene (the most potent carcinogenic PAH) be set at 0.2 µg/m^3 as an 8-hour TWA breathing zone concentration.

Conclusion: The results of PAH monitoring indicate that the exposure of the Asphalt Laboratory Technician during handling of the C320 + 6% HDPE/PP (Wet Method) was the highest exposure at 2.4 µg/m^3 over a period of 116 minutes and the second highest was during handling of C320 + 5% HDPE/PP (Dry Method) 0.93 µg/m^3 over a period of 116 minutes. It should be noted that the concentrations of PAHs over an 8-hour TWA basis would be expected to be significantly lower than indicated by the results of monitoring over the sampling period. All static samples in the Asphalt Laboratory had either non-detectable or just detectable levels of PAHs. Naphthalene (a non-carcinogenic and the most volatile PAH) was the only PAH detected in all samples during handling of asphalt mixes in the Asphalt Laboratory for both the personal and static samples. All levels of naphthalene were well below SafeWork Australia workplace exposure standard of 52 mg/m^3 (52,000 µg/m^3) with the highest level being 0.005% of the standard. Benz(a)pyrene (the most carcinogenically potent PAH) was not detected in any of the samples for the trial asphalt mixes nor were any of the other 14 priority PAHs. These results indicate that there is a negligible risk of exposure to PAHs during handling of unmodified C320 and polymer modified C320 mixes in the Asphalt Laboratory.

The result of personal exposure monitoring of the person undertaking blending of the binders in the Main Laboratory indicated that the PAH exposures during handling of unmodified C320, C320 + 6% Comingled and C320 + 6% SBS were similar at between 2.1 µg/m^3 and 2.5 µg/m^3 whilst the PAH exposure during blending of C320 + 6% EVA was below the limit of quantification. The reason for the lower PAH level during blending of EVA bitumen mix is unknown, but consistent with the comparatively lower PAH personal exposure result for the technician handling C320 + 6% EVA in the Asphalt Laboratory. Naphthalene was the only PAH detected in all the personal and static samples for all bitumen mixes in the Main Laboratory and benzo(a)pyrene was not detected in any of the samples. All personal sampling results were well below the naphthalene workplace exposure standard with the highest level being 0.005% of the standard. These results indicate that there is a negligible risk of exposure to PAHs during blending of unmodified C320 and polymer modified C320 blends in the Main Laboratory.

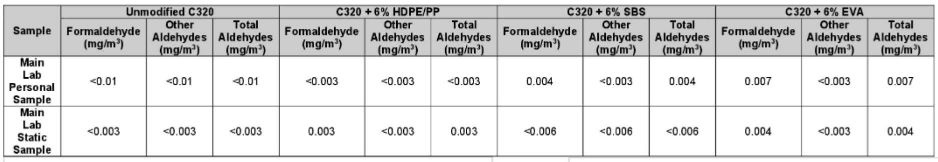
Aliphatic Aldehyde Results

Asphalt Laboratory Results

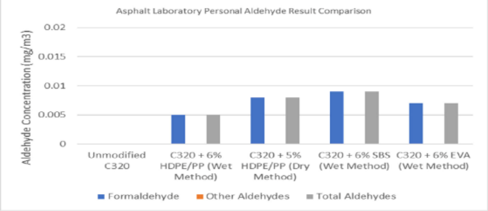


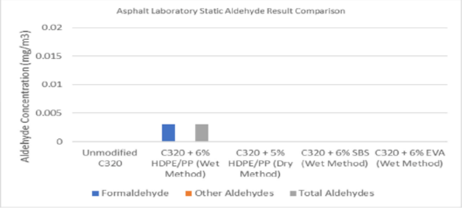
Sample	Unmodified C320			C320 + 6% HDPE/PP (Wet Method)			C320 + 5% HDPE/PP (Dry Method)			C320 + 6% SBS (Wet Method)			C320 + 6% EVA (Wet Method)		
	Formaldehyde (mg/m³)	Other Aldehydes (mg/m³)	Total Aldehydes (mg/m³)	Formaldehyde (mg/m³)	Other Aldehydes (mg/m³)	Total Aldehydes (mg/m³)	Formaldehyde (mg/m³)	Other Aldehydes (mg/m³)	Total Aldehydes (mg/m³)	Formaldehyde (mg/m³)	Other Aldehydes (mg/m³)	Total Aldehydes (mg/m³)	Formaldehyde (mg/m³)	Other Aldehydes (mg/m³)	Total Aldehydes (mg/m³)
Asphalt Lab Personal Sample	<0.004	<0.004	<0.004	0.005	<0.003	0.005	0.008	<0.002	0.008	0.009	<0.003	0.009	0.007	<0.006	0.007
Asphalt Lab Static Sample	<0.003	<0.003	<0.003	0.003	<0.003	0.003	<0.002	<0.002	<0.002	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006

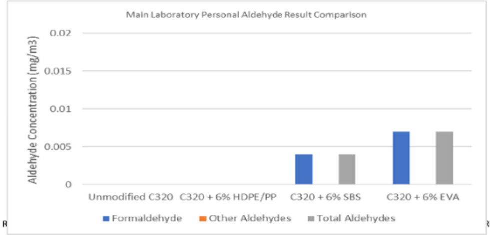
Main Laboratory Results

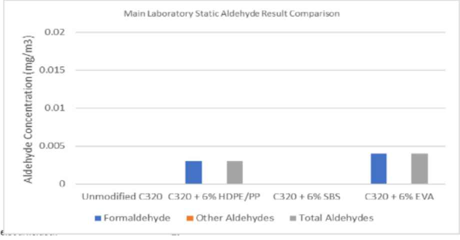


Sample	Unmodified C320			C320 + 6% HDPE/PP			C320 + 6% SBS			C320 + 6% EVA		
	Formaldehyde (mg/m³)	Other Aldehydes (mg/m³)	Total Aldehydes (mg/m³)	Formaldehyde (mg/m³)	Other Aldehydes (mg/m³)	Total Aldehydes (mg/m³)	Formaldehyde (mg/m³)	Other Aldehydes (mg/m³)	Total Aldehydes (mg/m³)	Formaldehyde (mg/m³)	Other Aldehydes (mg/m³)	Total Aldehydes (mg/m³)
Main Lab Personal Sample	<0.01	<0.01	<0.01	<0.003	<0.003	<0.003	0.004	<0.003	0.004	0.007	<0.003	0.007
Main Lab Static Sample	<0.003	<0.003	<0.003	0.003	<0.003	0.003	<0.006	<0.006	<0.006	0.004	<0.003	0.004









Comments: Aldehydes can be emitted when plastics are heated through a process of thermal decomposition. The most common aldehydes which are emitted as a result of thermal degradation of plastics are formaldehyde, acrolein and acetaldehyde. SafeWork Australia sets Workplace Exposure Standards for airborne substances in the breathing zone. The following table summarises the SafeWork Australia Workplace Exposure Standards for some aliphatic aldehydes which may be emitted during heating of plastics.

SafeWork Australia Workplace Exposure Standards for Aliphatic Aldehydes

Chemical	TWA~ Workplace Exposure Standard (mg/m^3)	TWA Workplace Exposure Standard (ppm)
Acrolein	0.23	0.1
Formaldehyde	1.2	1
Acetaldehyde	36	20
Crotonaldehyde	5.7	2
n-Valeraldehyde	176	50

~TWA = Average concentration over an 8-hour shift

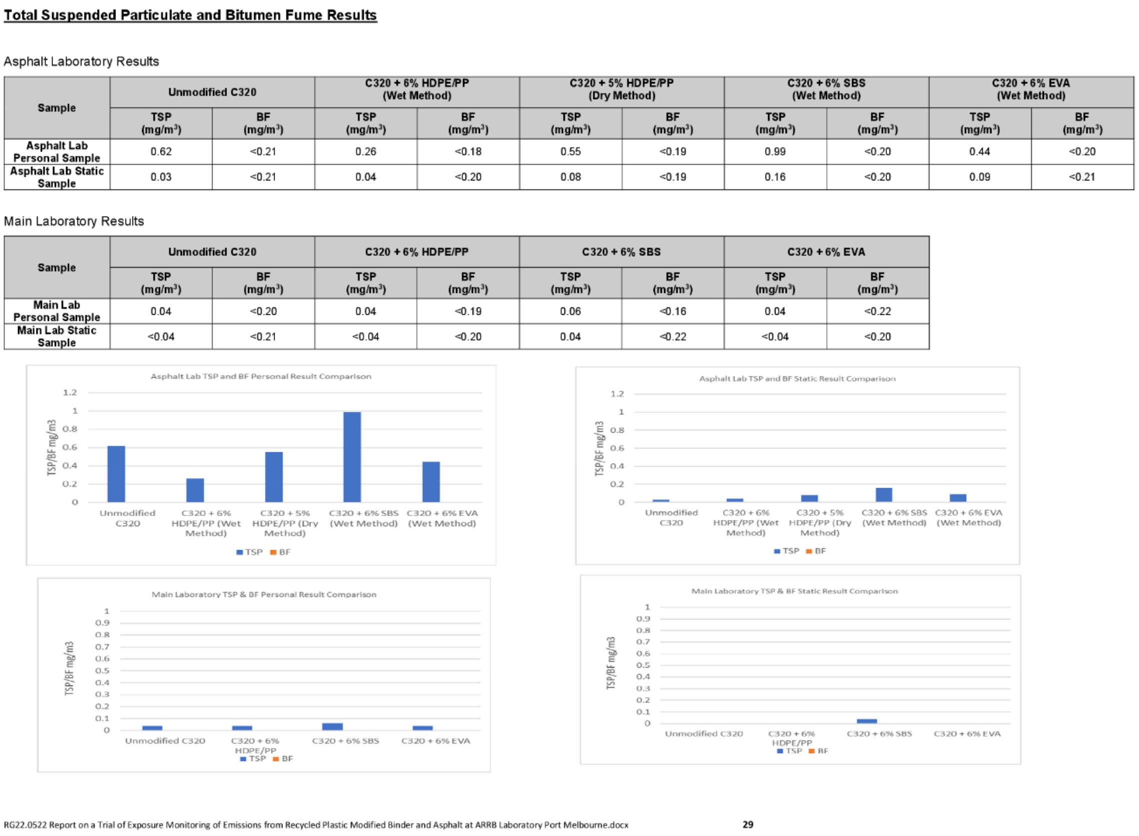
The highest levels of aldehydes detected in the breathing zone of the Asphalt Laboratory technician was during handling of C320 + 6% SBS at 0.009 mg/m^3, which exclusively comprised 0.009 mg/m^3 of formaldehyde. This represents 1.1% of the formaldehyde exposure standard. However, there appeared to be no significant difference in the formaldehyde exposure level between all the bitumen/plastics mixes which ranged between 0.005 mg/m^3 and 0.009 mg/m^3. The handling of unmodified C320 bitumen did not result in any detectable formaldehyde in the breathing zone of the Asphalt Laboratory technician. No other aldehydes besides formaldehyde were detected in any of the samples.

Only the handling of C320 + 6% HDPE/PP (wet method) showed detectable levels of formaldehyde in the static sample in the Asphalt Laboratory at a level of 0.003 mg/m^3.

The highest personal breathing zone formaldehyde concentration of the person undertaking blending in the Main Laboratory was 0.007 mg/m^3 for blending of C320 + 6% EVA. This level represents 0.6% of the formaldehyde workplace exposure standard. The highest concentration of formaldehyde for the static samples in the Main Laboratory was also during blending of C320 + 6% EVA at a level of 0.004 mg/m^3. No other aldehydes were detected in the static samples.

It should be noted that in all cases, the actual TWA exposure over an 8-hour workday would be significantly lower than indicated by the average concentration over the sampling period, assuming that no other exposure occurs.

Conclusion: All levels of aldehydes detected during handling of the various bitumen/plastic mixes in both the Asphalt Laboratory and Main Laboratory were well below the TWA SafeWork Australia Workplace Exposure Standards for formaldehyde, which was the only aldehyde species detected in any of the samples.



Total Suspended Particulate and Bitumen Fume Results

Asphalt Laboratory Results

Sample	Unmodified C320		C320 + 6% HDPE/PP (Wet Method)		C320 + 5% HDPE/PP (Dry Method)		C320 + 6% SBS (Wet Method)		C320 + 6% EVA (Wet Method)	
	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)
Asphalt Lab Personal Sample	0.62	<0.21	0.26	<0.18	0.55	<0.19	0.99	<0.20	0.44	<0.20
Asphalt Lab Static Sample	0.03	<0.21	0.04	<0.20	0.08	<0.19	0.16	<0.20	0.09	<0.21

Main Laboratory Results

Sample	Unmodified C320		C320 + 6% HDPE/PP		C320 + 6% SBS		C320 + 6% EVA	
	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)
Main Lab Personal Sample	0.04	<0.20	0.04	<0.19	0.06	<0.16	0.04	<0.22
Main Lab Static Sample	<0.04	<0.21	<0.04	<0.20	0.04	<0.22	<0.04	<0.20

Comments: TSP can be made up of aerosols consisting of solids (e.g. dust) and condensed liquids (e.g. mineral oils and other semi-volatile organic compounds) suspended in air. In the context of making up asphalt mixes in a laboratory environment, a significant amount of TSP would be expected to originate from the stone being added to the mixer. Because the composition of TSP can vary greatly, depending on its source, there are no specific exposure standards set in the working environment in Australia. SafeWork Australia recommends that, where no specific exposure standard has been assigned and the substance is both of inherently low toxicity and free from toxic impurities, exposure to Dusts Not Otherwise Classified (DNOC) should be maintained below 10 mg/m^3, measured as inhalable dust (8-hour TWA). Inhalable dust is that size range which can be inhaled and is nominally composed of particles of a size range 50% of which are less than 100 microns in mean equivalent aerodynamic diameter. TSP is of a wide range of particle sizes, some of which are in the inhalable range and also includes particles too large to be inhaled. The AIOH recommends a 'Dusts Not Otherwise Specified' (DNOS) trigger value of 5 mg/m^3 (inhalable fraction) be adopted to protect workers from potentially serious health effects due to insoluble or poorly water-soluble dusts of inherently low toxicity and free from toxic impurities and for which there is no other applicable Workplace Exposure Standard specified.

The results of personal monitoring of the Asphalt Laboratory Technician during handling of unmodified C320 various mixes of C320/plastic mixes indicated that the highest TSP exposure level was during making up of C320 + 6% SBS (Wet Method). However, the TSP levels did not vary significantly between the various mixes and any variations can be explained by differences in the handling and addition of the stone added to the bitumen mix. All TSP levels were well below the SafeWork Australia Workplace Exposure Limit for DNOC of 10 mg/m^3 and the AIOH recommended DNOS trigger value of 5 mg/m^3 (inhalable fraction). The static TSP levels were significantly lower than the personal monitoring results, suggesting that the particulate generation is dependent on the proximity to the source (e.g., standing over the mixes when the stone is added to the mixer).

The TSP exposure levels to the Main Laboratory person undertaking blending of the binders and the static sample levels were consistent between different blends and low at 0.4 to 0.6% of the DNOC exposure standard. This most probably reflects the fact that no stone is handled during blending and the exposure source of TSP is most likely from condensation of small amounts of semi-volatile components emitted from the hot bitumen.

Studies of asphalt working populations suggest that bitumen fumes are irritating to mucous membranes and that these symptoms increase with increasing temperature of the asphalt. SafeWork Australia has set a TWA workplace exposure standard for bitumen fume of 5 mg/m^3 which is measured by extracting condensed semi-volatile components from the TSP samples using cyclohexane (i.e., cyclohexane soluble fraction).

All BF levels for personal samples and static samples in the Asphalt and Main Laboratories were below the limit of quantitation of the method. These results indicate that the BF personal exposures during making up of various asphalt/plastic mixes and bitumen/plastic blending were below 4% of the SafeWork Australia Bitumen Fume Workplace Exposure Standard of 5 mg/m^3.

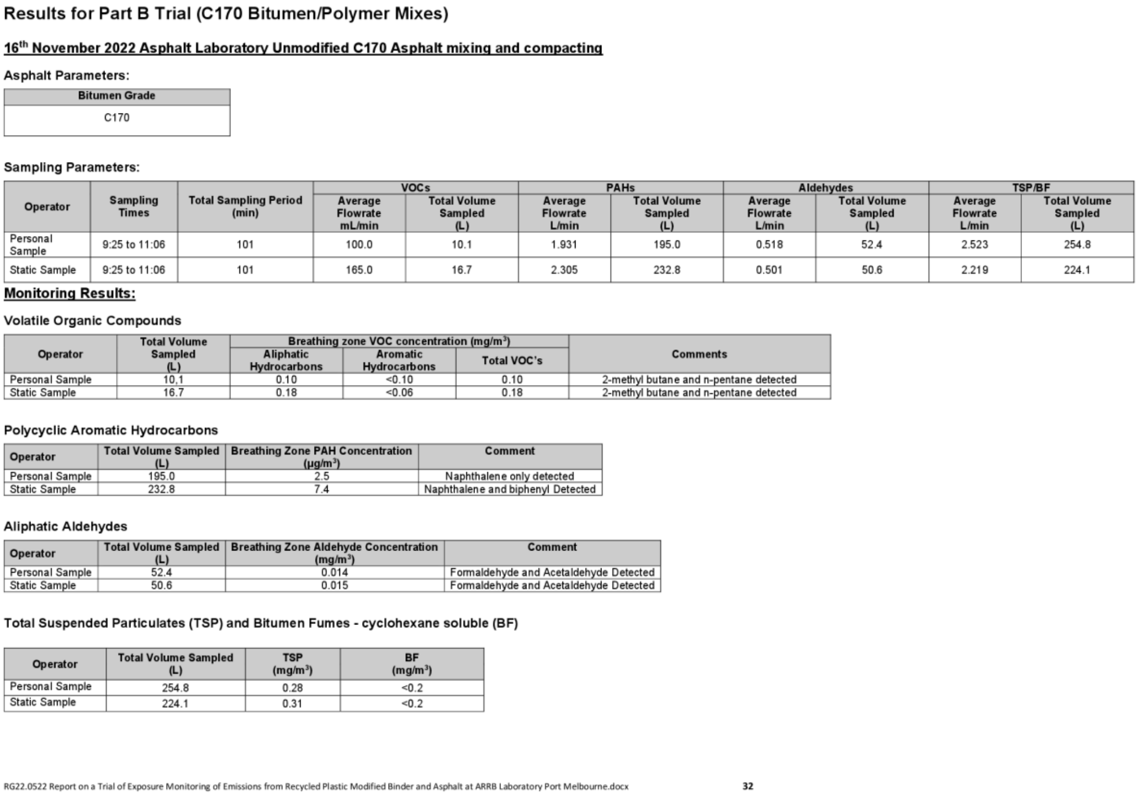
Conclusion: The results of monitoring of TSP and BF indicate that the exposure risks of the Asphalt Laboratory technician making up and handling various mixes of asphalt and of the Main Laboratory personnel undertaking blending of bitumen/plastics are negligible and well below the relevant workplace exposure standard.

Part B Trial

Part B Trial monitoring using C170 bitumen took place on 16th, 17th, 18th and 23rd November 2022 at the ARRB Facilities at 80a Turner St, Port Melbourne. The following activities were monitored during the three days of trials:

Date	Location	Product
16th November 2022	Asphalt Laboratory	Unmodified C170 Asphalt mixing and compacting
	Asphalt Laboratory	C170 + 0.3% EVA (Wet Method)
	Main Laboratory	Unmodified C170 Blending
17th November 2022	Asphalt Laboratory	C170 + 0.3% SBS (Wet Method) Asphalt mixing and compacting
	Asphalt Laboratory	C170 + 0.5% HDPE/PP (Wet Method) Asphalt mixing and compacting
	Main Laboratory	C170 + 6% EVA Blending
	Asphalt Laboratory	C170 + 1.5% HDPE/PP (Dry Method) Asphalt mixing and compacting
	Main Laboratory	C170 + 10% HDPE/PP Blending
18th November 2022	Main Laboratory	C170 + 6.5% SBS + 7% Combining oil Blending
	Main Laboratory	C170 + 10% LDPE Blending
23rd November 2022	Asphalt Laboratory	C170 + 0.5% LDPE (Wet Method) Asphalt mixing and compacting
	Asphalt Laboratory	C170 + 1.5% LDPE (Dry Method) Asphalt mixing and compacting

The personal and static monitoring methodology was the same as that followed for the Part A Trial, except that the static monitors in the Main Laboratory were placed within the fume cabinet (as opposed to the opening of the fume cupboard in the Part A trials) to provide an indication of the "worst-case" potential atmospheric emissions during the heating and sampling of the bituminous blends.



Results for Part B Trial (C170 Bitumen/Polymer Mixes)

16th November 2022 Asphalt Laboratory Unmodified C170 Asphalt mixing and compacting

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	9:25 to 11:06	101	100.0	10.1	1.931	195.0	0.518	52.4	2.523	254.8
Static Sample	9:25 to 11:06	101	165.0	16.7	2.305	232.8	0.501	50.6	2.219	224.1

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	10,1	0.10	<0.10	0.10	2-methyl butane and n-pentane detected
Static Sample	16.7	0.18	<0.06	0.18	2-methyl butane and n-pentane detected

Polycyclic Aromatic Hydrocarbons

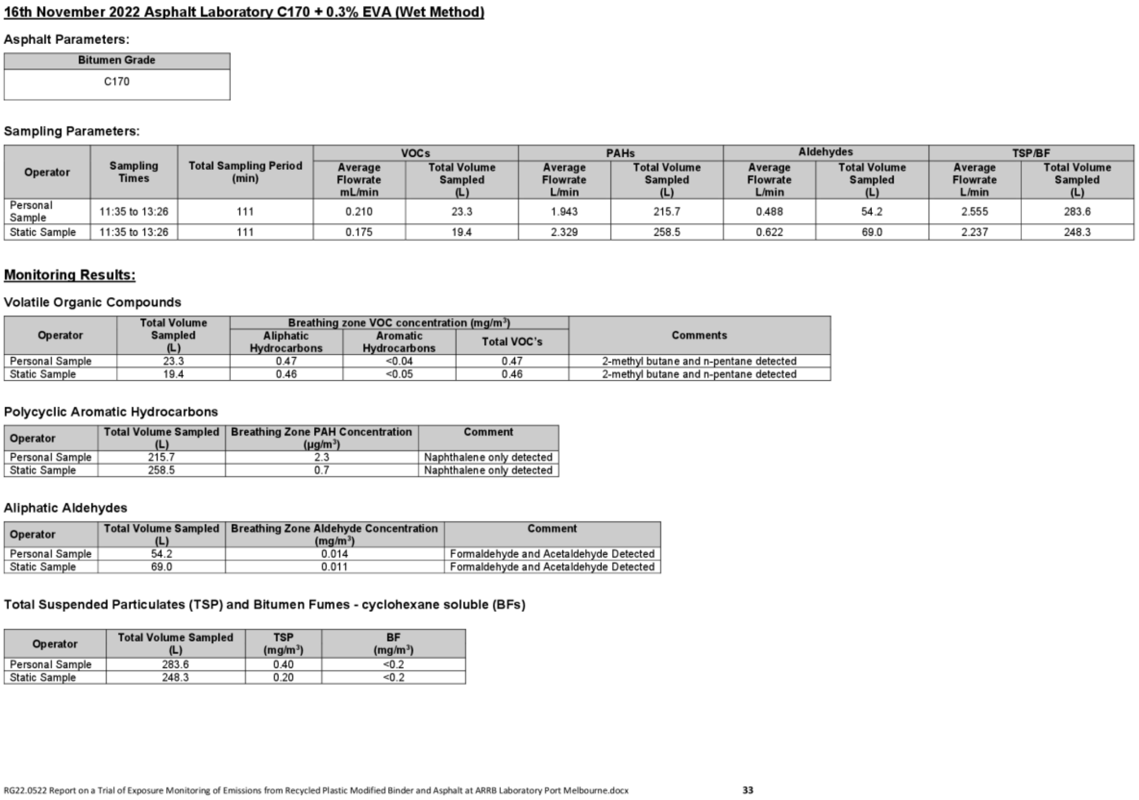
Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	195.0	2.5	Naphthalene only detected
Static Sample	232.8	7.4	Naphthalene and biphenyl Detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	52.4	0.014	Formaldehyde and Acetaldehyde Detected
Static Sample	50.6	0.015	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	254.8	0.28	<0.2
Static Sample	224.1	0.31	<0.2



16th November 2022 Asphalt Laboratory C170 + 0.3% EVA (Wet Method)

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	11:35 to 13:26	111	0.210	23.3	1.943	215.7	0.488	54.2	2.555	283.6
Static Sample	11:35 to 13:26	111	0.175	19.4	2.329	258.5	0.622	69.0	2.237	248.3

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	23.3	0.47	<0.04	0.47	2-methyl butane and n-pentane detected
Static Sample	19.4	0.46	<0.05	0.46	2-methyl butane and n-pentane detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	215.7	2.3	Naphthalene only detected
Static Sample	258.5	0.7	Naphthalene only detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	54.2	0.014	Formaldehyde and Acetaldehyde Detected
Static Sample	69.0	0.011	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	283.6	0.40	<0.2
Static Sample	248.3	0.20	<0.2

16th November 2022 Main Laboratory Unmodified C170 Blending

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	12:15 to 14:02	107	0.140	15.0	2.251	240.9	0.406	43.4	2.228	238.4
Static Sample	12:15 to 14:02	107	0.210	22.5	2.234	239.0	1.012	108.3	2.003	214.3

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	15.0	<0.07	<0.07	<0.07	No VOCs detected
Static Sample	22.5	<0.04	<0.04	<0.04	No VOCs detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	240.9	1.3	Naphthalene only detected
Static Sample	239.0	33	Naphthalene, Biphenyl, Acenaphthylene, Acenaphthene, Fluorene and Phenanthrene detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	43.4	0.006	Formaldehyde only detected
Static Sample	108.3	0.012	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	238.4	0.13	<0.2
Static Sample	214.3	0.23	<0.2

17th November 2022 Asphalt Laboratory C170 + 0.3% SBS (Wet Method) Mixing and Compacting

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	8:15 to 10:02	107	0.291	31.1	1.983	212.2	0.772	82.6	2.589	277.0
Static Sample	8:15 to 10:02	107	0.214	22.9	2.388	255.5	1.035	110.7	2.575	275.5

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	31.1	0.26	<0.03	0.26	2-methyl butane and n-pentane detected
Static Sample	22.9	0.35	<0.04	0.35	2-methyl butane and n-pentane detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	212.2	2.1	Naphthalene only detected
Static Sample	255.5	1.8	Naphthalene only detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	82.6	0.015	Formaldehyde and Acetaldehyde Detected
Static Sample	110.7	0.013	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	277.0	0.72	<0.2
Static Sample	275.5	0.40	<0.2

17th November 2022 Main Laboratory C170 + 6% EVA Blending

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	10:18 to 12:00	102	0.182	18.6	1.879	191.7	0.864	88.1	2.257	230.2
Static Sample	10:18 to 12:00	102	0.268	27.3	2.006	204.6	0.759	77.4	2.284	233.0

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	18.6	<0.05	<0.05	<0.05	No VOCs Detected
Static Sample	27.3	<0.04	<0.04	<0.04	No VOCs Detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	191.7	<0.5	No PAHs detected
Static Sample	204.6	52	Naphthalene, Biphenyl, Acenaphthylene, Acenaphthene, Fluorene and Phenanthrene detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	88.1	0.010	Formaldehyde and Acetaldehyde Detected
Static Sample	77.4	0.026	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	230.2	0.09	<0.2
Static Sample	233.0	0.20	<0.2

17th November 2022 Asphalt Laboratory C170 + 0.5% HDPE/PP (Wet Method) Mixing and Compacting

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	10:57 to 13:13	136	0.276	37.5	2.004	272.5	0.562	76.4	2.624	356.9
Static Sample	10:57 to 13:13	136	0.215	29.2	2.372	322.6	1.039	141.3	2.632	358.0

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	37.5	0.64	0.03	0.67	2-methyl butane, n-pentane, n-octane, n-nonane, n-decane and 1,2,4-trimethylbenzene detected
Static Sample	29.2	0.79	0.03	0.82	2-methyl butane, n-pentane, n-octane, n-nonane, n-decane and 1,2,4-trimetmthyl benzene detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	272.5	1.8	Naphthalene only detected
Static Sample	322.6	1.6	Naphthalene only detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	76.4	0.016	Formaldehyde and Acetaldehyde Detected
Static Sample	141.3	0.011	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	356.9	0.28	<0.2
Static Sample	358.0	0.59	<0.2

17th November 2022 Asphalt Laboratory C170 + 1.5% HDPE/PP (Dry Method) Mixing and Compacting

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	14:05 to 16:02	117	0.282	33.0	2.021	236.5	0.378	44.2	2.621	306.7
Static Sample	14:05 to 16:02	117	0.219	25.6	2.291	268.0	1.033	120.9	2.659	311.1

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	33.0	0.21	<0.03	0.21	2-methyl butane, n-pentane and n-nonane detected
Static Sample	25.6	0.16	<0.04	0.16	2-methyl butane and n-pentane detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	236.5	2.0	Naphthalene only detected
Static Sample	268.0	0.86	Naphthalene only detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	44.2	0.019	Formaldehyde and Acetaldehyde Detected
Static Sample	120.9	0.010	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	306.7	0.95	<0.2
Static Sample	311.1	0.32	<0.2

17th November 2022 Main Laboratory C170 + 10% HDPE/PP Blending

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	14:30 to 16:30	120	0.181	21.7	2.134	256.1	0.873	104.8	2.134	256.1
Static Sample	14:30 to 16:30	120	0.271	32.5	2.036	244.6	0.698	83.8	2.036	244.3

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	21.7	<0.05	<0.05	<0.05	No VOCs detected
Static Sample	32.5	<0.03	<0.03	<0.03	No VOCs detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	256.1	4.4	Naphthalene only detected
Static Sample	244.6	17	Naphthalene, Biphenyl, Acenaphthene and Fluorene detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	104.8	0.009	Formaldehyde and Acetaldehyde Detected
Static Sample	83.8	0.012	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	256.1	0.08	<0.2
Static Sample	244.3	0.18	<0.2

18th November 2022 Main Laboratory C170 + 6.5% SBS + 7% Combining oil Blending

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	10:53 to 12:43	110	0.183	20.1	2.014	221.5	0.877	96.5	2.278	250.6
Static Sample	10:53 to 12:43	110	0.282	31.0	1.748	192.3	0.724	79.6	2.291	252.0

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	20.1	0.05	<0.05	0.05	n-undecane only detected
Static Sample	31.0	<0.03	<0.03	<0.03	No VOCs detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	221.5	4.7	Naphthalene only detected
Static Sample	192.3	34	Naphthalene, Biphenyl, Acenaphthene, Phenanthrene and Fluorene detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	96.5	0.012	Formaldehyde and Acetaldehyde Detected
Static Sample	79.6	0.020	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	250.6	0.08	<0.20
Static Sample	252.0	0.32	<0.20

18th November 2022 Main Laboratory C170 + 10% LDPE Blending

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	14:48 to 16:48	120	0.182	21.8	2.022	242.6	0.899	107.9	2.285	274.2
Static Sample	14:48 to 16:48	120	0.276	33.1	2.051	246.1	0.737	88.4	2.044	245.3

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	21.8	<0.05	<0.05	<0.05	No VOCs detected
Static Sample	33.1	<0.03	<0.03	<0.03	No VOCs detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	242.6	2.8	Naphthalene only detected
Static Sample	246.1	10	Naphthalene, Biphenyl and Fluorene detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	107.9	0.014	Formaldehyde and Acetaldehyde Detected
Static Sample	88.4	0.025	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	274.2	0.07	<0.2
Static Sample	245.3	0.29	<0.2

23rd November 2022 Asphalt Laboratory C170 + 0.5% LDPE (Wet Method) Mixing and Compacting

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	8:58 to 10:49	111	0.210	23.2	2.120	235.3	0.503	55.8	2.269	251.9
Static Sample	8:58 to 10:49	111	0.376	41.8	1.946	216.0	0.483	53.6	2.366	262.6

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	23.2	<0.04	<0.04	<0.04	No VOCs detected
Static Sample	41.8	<0.02	<0.02	<0.02	No VOCs detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	235.3	1.9	Naphthalene only detected
Static Sample	216.0	1.2	Naphthalene only detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	55.8	0.016	Formaldehyde and Acetaldehyde Detected
Static Sample	53.6	0.013	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	251.9	0.40	<0.2
Static Sample	262.6	0.11	<0.2

23rd November 2022 Asphalt Laboratory C170 + 1.5% LDPE (Dry Method) Mixing and Compacting

Asphalt Parameters:

Bitumen Grade
C170

Sampling Parameters:

Operator	Sampling Times	Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
			Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
Personal Sample	11:59 to 14:05	126	0.214	27.0	2.115	266.5	0.454	57.2	2.284	287.8
Static Sample	11:59 to 14:05	126	0.368	46.4	2.355	296.7	0.503	63.4	1.982	249.7

Monitoring Results:

Volatile Organic Compounds

Operator	Total Volume Sampled (L)	Breathing zone VOC concentration (mg/m³)			Comments
		Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Total VOC's	
Personal Sample	27.0	<0.04	<0.04	<0.04	No VOCs detected
Static Sample	46.4	0.04	<0.02	0.04	2-methyl butane and n-pentane detected

Polycyclic Aromatic Hydrocarbons

Operator	Total Volume Sampled (L)	Breathing Zone PAH Concentration (µg/m³)	Comment
Personal Sample	266.5	2.2	Naphthalene only detected
Static Sample	296.7	0.84	Naphthalene only detected

Aliphatic Aldehydes

Operator	Total Volume Sampled (L)	Breathing Zone Aldehyde Concentration (mg/m³)	Comment
Personal Sample	57.2	0.017	Formaldehyde and Acetaldehyde Detected
Static Sample	63.4	0.013	Formaldehyde and Acetaldehyde Detected

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BFs)

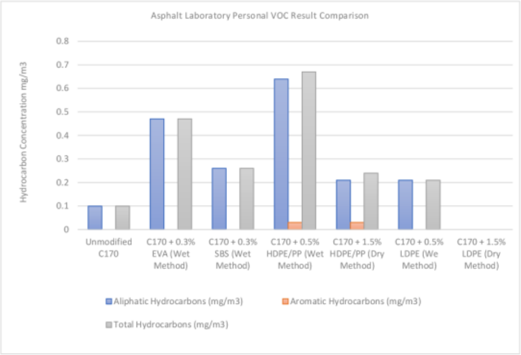
Operator	Total Volume Sampled (L)	TSP (mg/m³)	BF (mg/m³)
Personal Sample	287.8	0.35	<0.2
Static Sample	249.7	0.24	<0.2

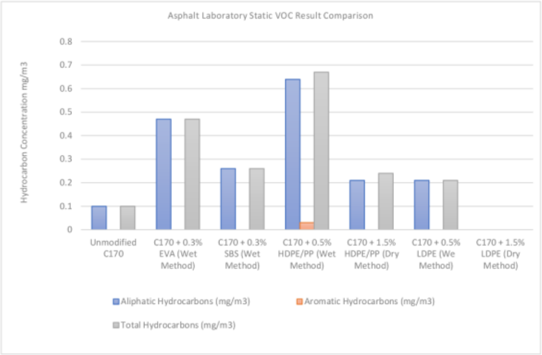
Discussion of Results

VOC Result Comparison

Asphalt Laboratory Results

Sample	Unmodified C170			C170 + 0.3% EVA (Wet Method)			C170 + 0.3% SBS (Wet Method)			C170 + 0.5% HDPE/PP (Wet Method)			C170 + 1.5% HDPE/PP (Dry Method)			C170 + 0.5% LDPE (Wet Method)			C170 + 1.5% LDPE (Dry Method)		
	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)
Asphalt Lab Personal Sample	0.10	<0.10	0.10	0.47	<0.04	0.47	0.26	<0.03	0.26	0.64	0.03	0.67	0.21	<0.03	0.21	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Asphalt Lab Static Sample	0.35	<0.06	0.35	0.46	<0.05	0.46	0.35	<0.04	0.35	0.79	0.03	0.82	0.16	<0.04	0.16	<0.02	<0.02	<0.02	0.04	<0.02	0.04

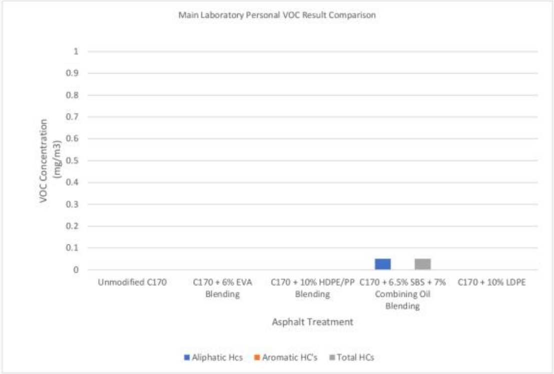


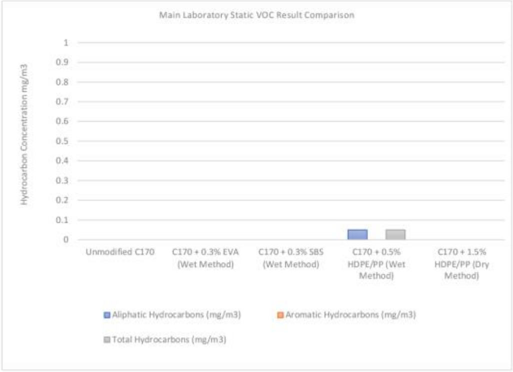


VOC Result Comparison continued

Main Laboratory Results

Sample	Unmodified C170			C170 + 6% EVA			C170 + 10% HDPE/PP			C170 + 6.5% SBS + 7% Combining oil			C170 + 10% LDPE		
	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)	Aliphatic Hydrocarbons (mg/m^3)	Aromatic Hydrocarbons (mg/m^3)	Total VOCs (mg/m^3)
Main Lab Personal Sample - Blending	<0.07	<0.07	<0.07	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	<0.05	0.05	<0.05	<0.05	<0.05
Main Lab Static Sample - Blending	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03





Comments: VOCs can be emitted when plastics are heated through a process of thermal decomposition. Additionally, bitumen can also emit petroleum hydrocarbons when heated. The composition of the VOCs is dependent on the chemical composition of plastic and on the temperature and includes both aliphatic and aromatic hydrocarbons. SafeWork Australia sets Workplace Exposure Standards for airborne substances in the breathing zone. The following table summarises the SafeWork Australia Workplace Exposure Standards for a selection of VOCs which may be emitted during heating of a bitumen/plastic mix.

SafeWork Australia Workplace Exposure Standards for selected VOCs

Chemical	TWA~ Workplace Exposure Standard (mg/m^3)	TWA Workplace Exposure Standard (ppm)
Pentane	1770	600
Hexanes	1760	500
n-hexane	72	20
Cyclohexane	350	100
Methyl Cyclohexane	1610	400
n-heptane	1640	400
Octane	1400	300
Nonane	1050	200
Benzene	3.2	1
Toluene	191	50
Xylene	350	80
Ethylbenzene	434	100
Styrene	213	50
Cumene	125	25
Trimethylbenzene	123	25
Total VOC (as White Spirit)	790	-

~TWA = Average concentration over an 8-hour shift

The highest levels of VOC detected in the breathing zone of the Asphalt Laboratory technician was during handling of C170 + HDPE/PP (Wet Method) at 0.67 mg/m^3, which comprised 0.22 mg/m^3 of n-pentane, 0.24 mg/m^3 of 2-methyl butane, 0.18 mg/m^3 of higher aliphatic hydrocarbons (n-octane to n-decane) and 0.03 mg/m^3 of trimethyl benzene. This represents 0.01% of the n-pentane exposure standard and 0.02% of the trimethyl benzene exposure standard (2-methyl butane does not have a set exposure standard) and 0.04% of the combined exposure standard for all VOCs.

The highest personal breathing zone concentration of the person undertaking blending in the Main Laboratory was 0.05 mg/m^3 for unmodified C170 + SBS + Combining oil blend. Undecane does not have a workplace exposure standard set by Safe Work Australia.

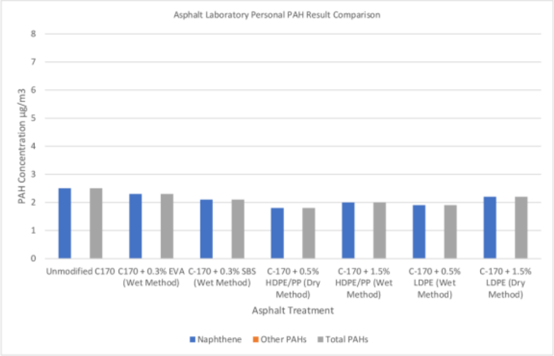
It should be noted that in all cases, the actual TWA exposure over an 8-hour workday would be significantly lower than indicated by the average concentration over the sampling period, assuming that no other exposure occurs.

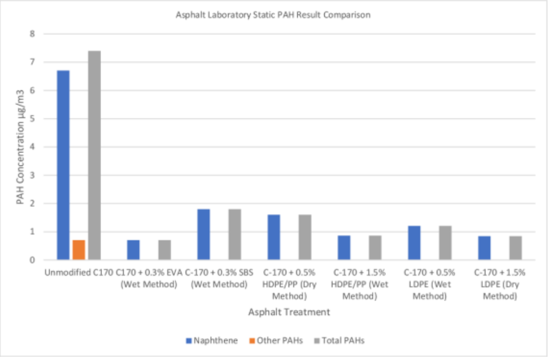
Conclusion: No significant amounts of VOCs were detected in any of the samples. All levels of VOCs detected during handling of the various C170 bitumen/plastic mixes in both the Asphalt Laboratory and Main Laboratory were well below the TWA SafeWork Australia Workplace Exposure Standards for individual VOCs and total VOCs.

PAH Result Comparison

Asphalt Laboratory Results

Sample	Unmodified C170			C170 + 0.3% EVA (Wet Method)			C-170 + 0.3% SBS (Wet Method)			C-170 + 0.5% HDPE/PP (Wet Method)			C-170 + 1.5% HDPE/PP (Dry Method)			C-170 + 0.5% LDPE (Wet Method)			C-170 + 1.5% LDPE (Dry Method)		
	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)
Asphalt Lab Personal Sample	2.5	<0.1	2.5	2.3	<0.1	2.3	2.1	<0.1	2.1	1.8	<0.1	1.8	2.0	<0.1	2.0	1.9	<0.1	1.9	2.2	<0.1	2.2
Asphalt Lab Static Sample	6.7	0.7	7.4	0.7	<0.1	0.7	1.8	<0.1	1.8	1.6	<0.1	1.6	0.86	<0.1	0.86	1.2	<0.1	1.2	0.84	<0.1	0.84

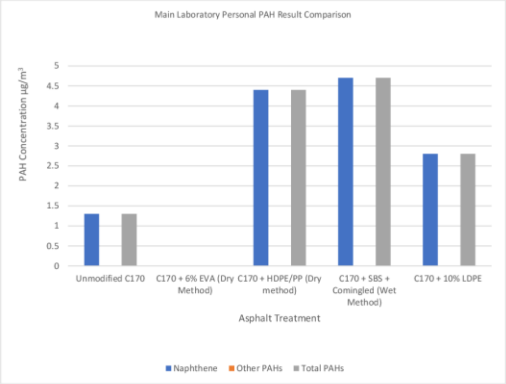


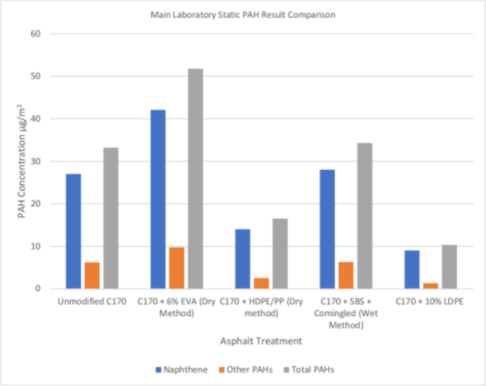


PAH Result Comparison continued

Main Laboratory Results

Sample	Unmodified C-170			C-170 + 6% EVA			C-170 + 10% HDPE/PP			C-170 + 6.5% SBS + 7% Combining oil			C-170 + 10% LDPE		
	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)	Naphthalene (µg/m³)	Other PAHs (µg/m³)	Total PAHs (µg/m³)
Main Lab Personal Sample - Blending	1.3	<0.1	1.3	<0.5	<0.5	<0.5	4.4	<0.1	4.4	4.7	<0.1	4.7	2.8	<0.1	2.8
Main Lab Static Sample - Blending	27	6.2	33	42	9.4	52	14	2.5	17	28	6.3	34	9.0	1.3	10





Comments: PAHs are molecules containing fused benzene ring systems. This structure includes the most basic two-ring naphthalene or four-ring pyrene and higher five-ring benzo(a)pyrene (B[a]P) and six-ring dibenzo(a,e)pyrene molecular compounds which are found in hundreds of PAH compounds. PAHs are present in crude oils and crude oil products in low concentrations. Bitumen consists of a complex mixture of organic compounds, including PAHs, which may vary in characteristics depending on the origin of the crude oil, refining process, and additives. Measurement of PAHs is undertaken by quantifying 17 PAHs identified by the US EPA as posing the greatest concern, several of which are known to be potentially carcinogenic to humans.

SafeWork Australia has set a workplace exposure standard for only one PAH, naphthalene – the simplest PAH - at 52 mg/m^3 (52,000 µg/m^3) as an 8-hour TWA concentration in the breathing zone. The AIOH recommends that a workplace exposure standard for benzo(a)pyrene (the most potent carcinogenic PAH) be set at 0.2 µg/m^3 as an 8-hour TWA breathing zone concentration.

Conclusion: The results of PAH monitoring indicate that the exposure of the Asphalt Laboratory Technician during handling of the unmodified C170 bitumen was the highest exposure at 2.5 µg/m^3. However, there was no significant difference in the personal total PAH exposures between different mixes of polymer and unmodified asphalt. Naphthalene (a non-carcinogenic and the most volatile PAH) was the only PAH detected in all samples during handling of asphalt mixes in the Asphalt Laboratory for both the personal samples. Naphthalene was the only PAH detected in the static samples in the Asphalt Laboratory, except for the unmodified C170 which also had a trace of biphenyl. All levels of naphthalene were well below SafeWork Australia workplace exposure standard of 52 mg/m^3 (52,000 µg/m^3) with the highest level being 0.005% of the standard. Benz(a)pyrene (the most carcinogenically potent PAH) was not detected in any of the samples for the trial asphalt mixes. These results indicate that there is a negligible risk of exposure to PAHs during handling of unmodified C170 and polymer modified C170 mixes in the Asphalt Laboratory. It should be noted that the concentrations of PAHs over an 8-hour TWA basis would be expected to be significantly lower than indicated by the results of monitoring over the sampling period.

The result of personal exposure monitoring in the Main Laboratory indicated that naphthalene was the only PAH detected during blending of unmodified and of the polymer blended asphalt samples. No PAHs were detected in the personal sample during blending of C170 + 6% EVA. The highest naphthalene concentration in the personal samples was 4.7 µg/m^3 which is 0.009% of the workplace exposure standard. The reason for the non-detection of PAHs during blending of the C170 + 6%EVA blend is unknown. Benzo(a)pyrene was not detected in any of the samples.

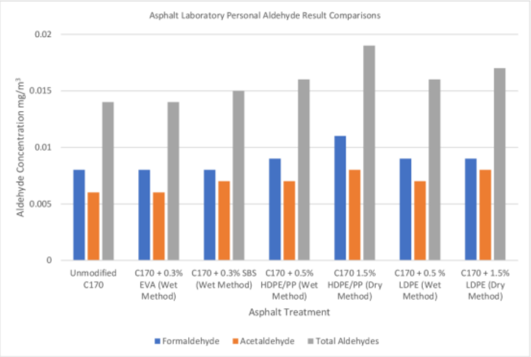
The results of the static sampling inside the fume cupboard indicated that the highest level of total PAH was detected during blending of C170 + 6% EVA with naphthalene (42 µg/m^3) making up 80.8% of the total. Benzo(a)pyrene was not detected in any of the samples. Other PAHs were detected in all static samples including biphenyl, acenaphthylene, acenaphthene, fluorene and phenanthrene.

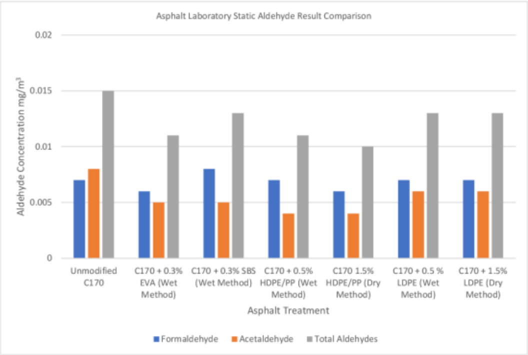
These results indicate that there is a negligible potential exposure to PAHs during blending of unmodified C170 and polymer modified C170 blends in the Main Laboratory.

Aldehyde Result Comparison

Asphalt Laboratory Results

Sample	Unmodified C170			C170 + 0.3% EVA (Wet Method)			C170 + 0.3% SBS (Wet Method)			C170 + 0.5% HDPE/PP (Wet Method)			C170 + 1.5% HDPE/PP (Dry Method)			C170 + 0.5% LDPE (Wet Method)			C170 + 1.5% LDPE (Dry Method)		
	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)
Asphalt Lab Personal Sample	0.008	0.006	0.014	0.008	0.006	0.014	0.008	0.007	0.015	0.009	0.007	0.016	0.011	0.008	0.019	0.009	0.007	0.016	0.009	0.008	0.017
Asphalt Lab Static Sample	0.007	0.008	0.015	0.006	0.005	0.011	0.008	0.005	0.013	0.007	0.004	0.011	0.006	0.004	0.010	0.007	0.006	0.013	0.007	0.006	0.013

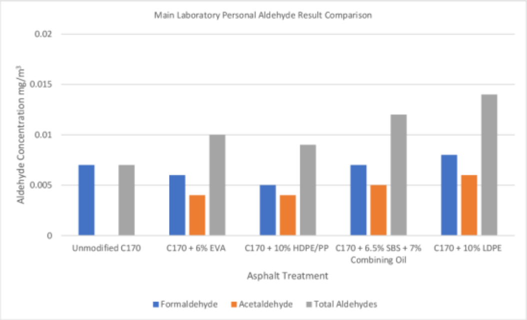


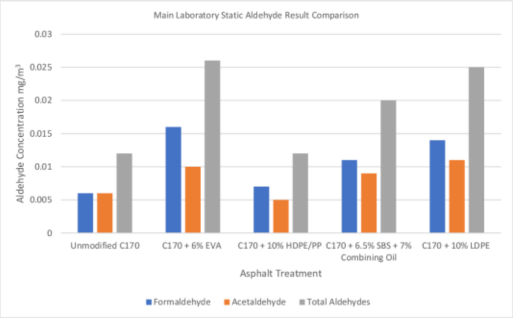


Aldehyde Result Comparison continued

Main Laboratory Results

Sample	Unmodified C170			C170 + 6% EVA			C170 + 10% HDPE/PP			C170 + 6.5% SBS + 7% Combining oil			C170 + 10% LDPE		
	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)	Formaldehyde (mg/m³)	Acetaldehyde (mg/m³)	Total Aldehydes (µg/m³)
Main Lab Personal Sample - Blending	0.007	<0.006	0.007	0.006	0.004	0.010	0.005	0.004	0.009	0.007	0.005	0.012	0.008	0.006	0.014
Main Lab Static Sample - Blending	0.006	0.006	0.012	0.016	0.010	0.026	0.007	0.005	0.012	0.011	0.009	0.020	0.014	0.011	0.025





Comments: Aldehydes can be emitted when plastics are heated through a process of thermal decomposition. The most common aldehydes which are emitted as a result of thermal degradation of plastics are formaldehyde, acrolein and acetaldehyde. SafeWork Australia sets Workplace Exposure Standards for airborne substances in the breathing zone. The following table summarises the SafeWork Australia Workplace Exposure Standards for some aliphatic aldehydes which may be emitted during heating of a plastic.

SafeWork Australia Workplace Exposure Standards for Aliphatic Aldehydes

Chemical	TWA~ Workplace Exposure Standard (mg/m^3)	TWA Workplace Exposure Standard (ppm)
Acrolein	0.23	0.1
Formaldehyde	1.2	1
Acetaldehyde	36	20
Crotonaldehyde	5.7	2
n-Valeraldehyde	176	50

~TWA = Average concentration over an 8-hour shift

The highest levels of aldehydes detected in the breathing zone of the Asphalt Laboratory technician was during handling of C170 + HDPE/PP at 0.019 mg/m^3, which comprised 0.011 mg/m^3 of formaldehyde and 0.008 mg/m^3 of acetaldehyde. This represents 1.6% of the formaldehyde exposure standard and 0.02% of the acetaldehyde exposure standard. There appeared to be no significant difference in the formaldehyde exposure level between all of the bitumen/plastics mixes (including the unmodified C170 bitumen) which ranged between 0.008 mg/m^3 and 0.011 mg/m^3. No other aldehydes besides formaldehyde and acetaldehyde were detected in any of the samples.

The results of static monitoring in the asphalt laboratory showed levels of formaldehyde between 0.006 mg/m^3 and 0.008 mg/m^3 for the unmodified bitumen and C170/polymer mixes, which were not significantly different from the personal breathing zone samples. Likewise, the levels of acetaldehyde ranged from 0.004 mg/m^3 and 0.008 mg/m^3.

The highest personal breathing zone formaldehyde concentration of the person undertaking blending in the Main Laboratory was 0.008mg/m^3 for blending of C170 + LDPE. This level represents 0.7% of the formaldehyde workplace exposure standard. The highest level of acetaldehyde exposure was also detected during blending of C170 + LDPE at 0.006 mg/m^3, which is 0.02% of the acetaldehyde exposure standard. The highest concentration of formaldehyde for the static samples in the Main Laboratory was also during blending of C170 + 6% EVA at a level of 0.016 mg/m^3 whilst the highest level of acetaldehyde was detected during blending of C170 and LDPE at 0.011 mg/m^3.

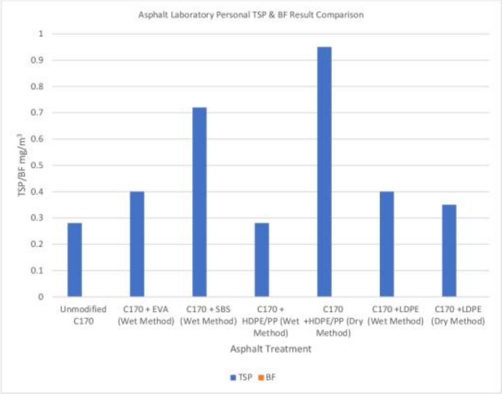
It should be noted that in all cases, the actual TWA exposure over an 8-hour workday would be significantly lower than indicated by the average concentration over the sampling period, assuming no other exposure occurs.

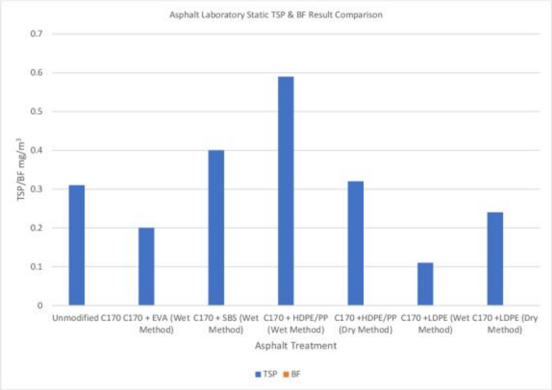
Conclusion: All levels of aldehydes detected during handling of the various C170 bitumen/plastic mixes in both the Asphalt Laboratory and Main Laboratory were well below the Time-Weighted Average SafeWork Australia Workplace Exposure Standards for formaldehyde, which was the only aldehyde species detected in any of the samples.

TSP and Bitumen Fume (BF) Result Comparison

Asphalt Laboratory Results

Sample	Unmodified C170		C170 + 0.3% EVA (Wet Method)		C170 + 0.3% SBS (Wet Method)		C170 + 0.5% HDPE/PP (Wet Method)		C170 + 1.5% HDPE/PP (Dry Method)		C170 + 0.5% LDPE (Wet Method)		C170 + 1.5% LDPE (Dry Method)	
	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)
Asphalt Lab Personal Sample	0.28	<0.2	0.40	<0.2	0.72	<0.2	0.28	<0.2	0.95	<0.2	0.40	<0.2	0.35	<0.2
Asphalt Lab Static Sample	0.31	<0.2	0.20	<0.2	0.40	<0.2	0.59	<0.2	0.32	<0.2	0.11	<0.2	0.24	<0.2

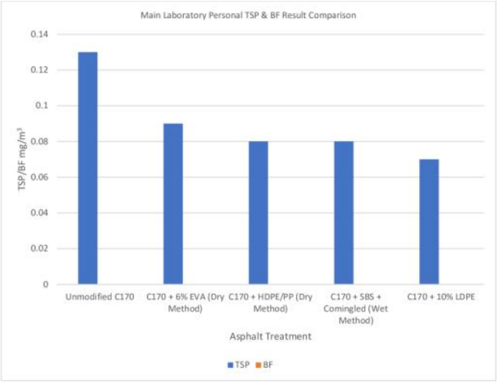


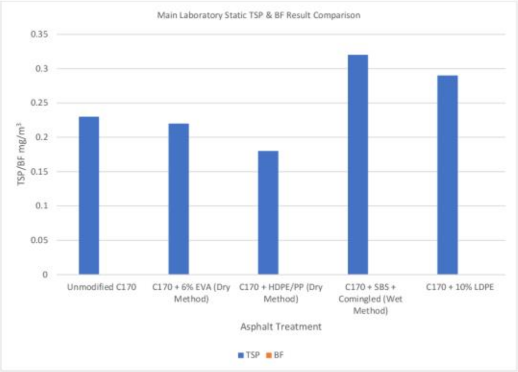


TSP and Bitumen Fume (BF) Result Comparison continued

Main Laboratory Results

Sample	Unmodified C170		C170 + 6% EVA		C170 + 10% HDPE/PP		C170 + 6.5% SBS + 7% Combining oil		C170 + 10% LDPE	
	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)	TSP (mg/m^3)	BF (mg/m^3)
Main Lab Personal Sample - Blending	0.13	<0.2	0.09	<0.2	0.08	<0.2	0.08	<0.2	0.07	<0.2
Main Lab Static Sample - Blending	0.23	<0.2	0.22	<0.2	0.18	<0.2	0.32	<0.2	0.29	<0.2





Comments: TSP can be made up of aerosols consisting of solids (e.g., dust) and condensed liquids (e.g., mineral oils and other semi-volatile organic compounds) suspended in air. In the context of making up asphalt mixes in a laboratory environment, a significant amount of TSP would be expected to originate from the stone being added to the mix. Because the composition of TSP can vary greatly, depending on its source, there are no specific exposure standards set in the working environment in Australia. SafeWork Australia recommends that, where no specific exposure standard has been assigned and the substance is both of inherently low toxicity and free from toxic impurities, exposure to DNOC should be maintained below 10 mg/m^3, measured as inhalable dust (8-hour TWA). Inhalable dust is that size range which can be inhaled and is nominally composed of particles of a size range 50% of which are less than 100 microns in mean equivalent aerodynamic diameter. TSP is of a wide range of particle sizes, some of which are in the inhalable range and also includes particles too large to be inhaled. The AIOH recommends a DNOS trigger value of 5 mg/m^3 (inhalable fraction) be adopted to protect workers from potentially serious health effects due to insoluble or poorly water-soluble dusts of inherently low toxicity and free from toxic impurities and for which there is no other applicable Workplace Exposure Standard specified.

The results of personal monitoring of the Asphalt Laboratory Technician during handling of unmodified C170 and various mixes of C170/plastic indicated that the highest TSP exposure level was during making up of C170 + HDPE/PP (Dry Method) at 0.95 mg/m^3. The TSP levels varied between 0.28 mg/m^3 and 0.95 mg/m^3. All TSP levels were well below the SafeWork Australia Workplace Exposure Limit for DNOC of 10 mg/m^3 and the AIOH recommended DNOS trigger value of 5 mg/m^3 (inhalable fraction) with the highest TSP level being 9.5% of the exposure standard. The static TSP levels varied between 0.11 mg/m^3 and 0.59 mg/m^3.

The TSP exposure levels to the Main Laboratory person undertaking blending of the binders varied between 0.13 mg/m^3 for the unmodified C170 bitumen (1.3% of the exposure standard) to 0.07 mg/m^3 for the C170 + 10% LDPE blend. The static sampling results were consistent among different blends and were between 1.8% to 3.2% of the DNOC exposure standard. This most probably reflects the fact that no stone is handled during blending of the binders and the exposure source of TSP is most likely from condensation of small amounts of semi-volatile components emitted from the hot bitumen.

SafeWork Australia has set a TWA workplace exposure standard for BF of 5 mg/m^3 which is measured by extracting condensed semi-volatile components from the TSP samples using cyclohexane (i.e., cyclohexane soluble fraction).

All BF levels for personal samples and static samples in the Asphalt and Main Laboratories were below the limit of quantitation of the method. Likewise, all personal and static samples for the Main Laboratory trials were below the limit if quantitation. These results indicate that the BF personal exposures during making up of various asphalt/plastic mixes and bitumen/plastic blending were below 4% of the SafeWork Australia Bitumen Fume Workplace Exposure Standard of 5 mg/m^3.

Conclusion: The results of monitoring of TSP and BF indicate that the exposure risks of the Asphalt Laboratory technician making up and handling various mixes of asphalt and of the Main Laboratory personnel undertaking blending of bitumen/plastics mixes are negligible and well below the relevant workplace exposure standard.

B.2 Absolute Fumes and Emissions

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Report on a Laboratory Trial of Exposure Monitoring of Emissions from Recycled Plastic Modified Binder using an Enclosed Fume Emission Generation Chamber (modified Brandt Apparatus) at ARRB Laboratory Port Melbourne

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Report Date: 21st July 2023

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Introduction

As part of an ARRB-lead project on laboratory-based fume emissions sampling and testing, AMCOSH Pty Ltd undertook headspace sampling of airborne fume emissions during blending of bitumen to which various virgin and recycled plastics had been added.

The purpose of the project was to identify whether there were any differences in the airborne emissions from the blends containing recycled plastics when compared to commonly used materials. Sampling and analysis of the following emissions in the head-space of the fume emissions test chamber were undertaken for a range of bitumen/plastic blends:

- Volatile organic compounds (VOCs)/Petroleum hydrocarbons
- Bitumen Fumes (BF) and Total Suspended Particulates (TSP)
- Polycyclic Aromatic Compounds (PAHs) and;
- Aldehydes.

For consistency and to allow for direct comparison of fume emissions between the various blends, C170 grade bitumen from the same supplier was used throughout the trials. The following blends were used in this project:

- Unmodified C170
- C170 + 6% EVA
- C170 + 6.5% SBS + 7% Combining Oil
- C170 + 10% LDPE
- C170 + 10% HDPE/PP

The C170 bitumen samples to which recycled plastics were added were pre-heated in an oven to 150ºC and 500 grams of each bitumen blend was carefully weighed on a top-loading balance whilst being transferred into the fume generation chamber flask.

Bitumen Fume Generation Methodology

Bitumen Fume Generation

A fume generation chamber based on a modification of the Brandt apparatus was used to sample the emissions in the headspace of the bitumen samples to which recycled plastics were added. The apparatus consisted of a 5-necked, 5000 mL flat bottom borosilicate glass reaction flask of the sort indicated in Figure 1 below:

Figure 1 – 5-necked flat bottom reaction flask used in fume emission trials (modified Brandt apparatus)

The flask was placed into a heating mantle inside a fume cabinet and the impeller inserted through the central neck of the flask to below the level of the molten binder. A thermocouple was placed into one of the side necks of the flask with the sensing tip submerged beneath the molten binder. The heating mantle was turned on and the impeller activated to stir the bitumen blend. The temperature of the blend was continuously monitored until the desired temperature (approximately 180°C) was reached. Once at the desired temperature, the speed of the impeller was set to 1000 RPM and the fume sampling devices were placed in the headspace of the flask through the remaining three neck openings and sampling commenced. Simultaneous sampling of all 4 types of emissions was undertaken over a period of 60 minutes. For those particulate-based emissions which were sampled onto filters housed in cassettes (BF, TSP, PAHs), short lengths of Teflon tubing were connected to the cassettes to ensure that the samples were drawn from the headspace of the flasks at approximately the same distance from the surface of the molten binders. Cold gel packs were used to cool the sampling tubes which were used to sample gaseous emissions in order to reduce the potential loss of gases due to overheating of the sorbent material from the hot gases. The setup of the experimental apparatus is illustrated in Figure 2 below

Figure 2 – Setup of fume generation chamber inside fume cupboard

Figure 3 shows the setup for the sampling of fume emissions in the headspace of the flask. Note that aluminium foil was used to wrap the exposed areas of the flask so as to try to reduce heat losses and maintain a constant headspace temperature in order to avoid condensation of fumes onto the wall of the flask.

Figure 3 – Setup of headspace sampling emission train

The temperatures of the blends in each trial were kept within a narrow range of 165ºC to 189ºC over the 60-minute sampling period to reduce the variations in emission rates due to temperature fluctuations of the bitumen blends. The temperature of the blends from the thermocouple were recorded every five minutes during the sampling period. The temperature ranges of each of the blends over the sampling period are summarised in Table 1:

Table 1: Temperature of bitumen blends used in the headspace emissions trials

Bitumen Blend	Average Temperature (ºC)	Temperature Range (ºC)
Unmodified C170	184	179 -186
C170 + 6% EVA	180	175 -188
C170 + 6.5% SBS + 7% Combining Oil	177	165 -184
C170 + 10% LDPE	179	172 - 189
C170 + 10% HDPE/PP	181	174 - 185

Sampling and Analysis Methodology

The following sampling methods were used for the four types of potential emissions from the surface of the binders in the headspace of the flasks during the trials. Note that blank filters and tubes were submitted with each batch of samples to the laboratory to determine any background/residual contaminants present in the sampling media or contamination during handling and transport of samples.

Volatile Organic Compounds (VOCs)/Petroleum Hydrocarbons

Sampling for VOCs was undertaken by drawing air through activated coconut shell charcoal tubes (SKC Anasorb CSC 200mg/400mg sorbent Part Number 226-09) using SKC5000 personal sampling pumps at a flowrate of approximately 500 ml per minute in accordance with NIOSH Method 1500 (Hydrocarbons, BP 36°-216 °C), NIOSH Method 1501 (Hydrocarbons, Aromatic) and Australian Standard AS 2986.1-2003: Workplace air quality - Sampling and analysis of volatile organic compounds by solvent desorption/gas chromatography - Pumped sampling method.

Following sampling, the samples were refrigerated until they were dispatched for laboratory analysis. All VOC samples were analysed by TestSafe Australia (the chemical analysis branch of SafeWork NSW) by the method of solvent desorption with carbon disulphide and analysis by gas chromatography/mass spectrometry by method WCA.2.07 Analysis of Volatile Organic Compounds in Workplace Air by Gas Chromatography/Mass Spectrometry. TestSafe Australia is NATA accredited for this method (Accreditation No 3726) in compliance with ISO/IEC Standard 17025-Testing. The analytical method has a limit of quantitation of 1 µg per tube (LOQ - the lowest amount of VOC which can be quantitated per tube with 95% confidence). One tube was used per monitoring trial.

Polycyclic Aromatic Hydrocarbons (PAHs)

Sampling of PAHs in the headspace was undertaken by drawing air using SKC5000 personal sampling pumps at a flowrate of approximately 2.0 litres per minute through a pre-weighed PTFE filter to collect particulate matter with an XAD-2 solid sorbent sampling tube (XAD-2, 2 sections, 50/100 mg sorbent SKC Part Number 226-30-04) connected at the rear of the filter cassette to collect volatile (gaseous) PAHs in accordance with NIOSH Method 5800 Polycyclic Aromatic Compounds.

Following sampling, the samples were refrigerated until they were dispatched for laboratory analysis. The samples were analysed for PAHs by TestSafe Australia (the chemical analysis branch of SafeWork NSW) by the method of solvent desorption and analysis by gas chromatography/mass spectrometry by method WCA 178 Analysis of Polycyclic Aromatic Hydrocarbons in Air by Gas Chromatography/Triple Quadrupole Mass Spectrometer. The limit of reporting (LOR) for the PAH analysis was 0.1 µg per filter/tube. One filter/tube combination was used per monitoring trial.

Aldehydes

Sampling for aldehydes in the headspace of the fume generation apparatus undertaken by drawing air using SKC5000 personal sampling pumps at a flowrate of approximately 100-150 mL per minute through a 2,4-dinitropheylhydrazone (DNPH) treated silica gel tubes (High-purity Silica Gel (ultra-low background), treated with (2,4-dinitrophenylhydrazine) SKC Part Number 226-119) to collect and derivatise aliphatic aldehydes in accordance with NIOSH Method 2018 Aliphatic Aldehydes in Air.

Following sampling, the samples were refrigerated until they were dispatched for laboratory analysis. The samples were analysed by TestSafe Australia by the method of solvent extraction with acetonitrile and High-Performance Liquid Chromatography (HPLC). The LOQ for aliphatic aldehydes was 0.25 µg per tube. One tube was used per monitoring trial.

Total Suspended Particulates (TSP) and Bitumen Fume (BF)

Sampling for TSP and BF was undertaken in the headspace of the fume generation apparatus by drawing air using SKC5000 personal sampling pumps at a flowrate of approximately 2.0 per minute through a pre-weighed PTFE filter housed in a three-piece polycarbonate cassette (supplied by SIMTARS) in accordance with NIOSH Method 5040.

Following sampling, the samples were refrigerated until they were dispatched for laboratory analysis. All TSP/BF samples were analysed by SIMTARS (Safety in Mines Testing and Research Station) Queensland by gravimetry and by solvent extraction using cyclohexane. The LOR for TSP is 0.01 mg and for BF is 0.05 mg per filter. One filter was used per monitoring trial.

Results

1. Trial 1 Unmodified C170 Bitumen

Sampling Parameters:

Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
	Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
60	501	30.03	1.991	119.43	114	6.84	1.959	117.5

Headspace Monitoring Results:

Volatile Organic Compounds

Aliphatic Hydrocarbons	Mass of Aliphatic VOC on tube (µg)	Aliphatic VOC Concentration in headspace (mg/m³)	Aromatic Hydrocarbons	Mass of Aromatic VOC on tube (µg)	Aromatic VOC Concentration in headspace (mg/m³)
2-Methylbutane	8	0.266	Benzene	3	0.100
n-Pentane	15	0.500	Ethylbenzene	11	0.366
2-Methylpentane	8	0.266	Isopropylbenzene	2	0.067
3-Methylpentane	4	0.133	1,2,3-Trimethylbenzene	32	1.066
Cyclopentane	3	0.100	1,2,4-Trimethylbenzene	73	2.431
Methyl cyclopentane	5	0.167	1,3,5-Trimethylbenzene	20	0.666
2,3-Dimethylpentane	5	0.167	Styrene	ND	ND
n-Hexane	18	0.599	Toluene	21	0.699
3-Methylhexane	8	0.266	p-Xylene &/or m-Xylene	43	1.432
Cyclohexane	7	0.233	o-Xylene	23	0.766
Methylcyclohexane	8	0.266	**Total Aromatic HCs**	**228**	**7.592**
2,2,4-Trimethylpentane	ND	ND			
n-Heptane	24	0.799			
n-Octane	31	1.032			
n-Nonane	49	1.632			
n-Decane	75	2.498			
n-Undecane	115	3.830			
n-Dodecane	185	6.161			
n-Tridecane	299	9.957			
n-Tetradecane	327	10.889			
TOTAL Aliphatic HCs	**1194**	**39.760**			

Polycyclic Aromatic Hydrocarbons

PAH	Total Mass of PAHs collected (filter + tube) µg	Total PAH Concentration in headspace (mg/m³)
Naphthalene	302	2.529
Biphenyl	171.7	1.438
Acenaphthylene	20.5	0.172
Acenaphthene	106.8	0.894
Fluorene	97	0.812
Phenathrene	28	0.234
Anthracene	ND	ND
Fluorathene	ND	ND
Pyrene	1.6	0.013
Benz(a)anthracene	0.2	0.002
Chrysene	0.5	0.004
Benzo(b)fluoranthrene	ND	ND
Benzo(k)fluoranthrene	ND	ND
Benzo(a)pyrene	ND	ND
Indeno(1,2,3-cd) pyrene	ND	ND
Bibenz(a,h)anthracene	ND	ND
Benzo(g,h,i)perylene	ND	ND
TOTAL PAHs	**728.3**	**6.098**

+ Note: some breakthrough of the more volatile PAHs was observed from the front to the rear section of the XAD-2 tube

Aliphatic Aldehydes

Aliphatic Aldehyde Results	Mass of Aliphatic Aldehyde on tube (µg)	Aliphatic Aldehyde Concentration in headspace (mg/m³)
Formaldehyde	1.53	0.22
Acetaldehyde	9.43	1.38
Crotonaldehyde	ND	ND
Valeraldehyde	ND	ND

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

TSP on filter (mg)	TCP Concentration in headspace (mg/m3)	BF on filter(mg)	BF Concentration in headspace(mg/m³)
12	102.1	11	93.6

2. Trial 2 C170 + 6% EVA

Sampling Parameters:

Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
	Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
60	524	31.4	2.016	120.9	128	7.70	1.950	117.0

Headspace Monitoring Results:

Volatile Organic Compounds

Aliphatic Hydrocarbons	Mass of Aliphatic VOC on tube (µg)	Aliphatic VOC Concentration in headspace (mg/m³)	Aromatic Hydrocarbons	Mass of Aromatic VOC on tube (µg)	Aromatic VOC Concentration in headspace (mg/m³)
2-Methylbutane	2	0.064	Benzene	ND	ND
n-Pentane	3	0.095	Ethylbenzene	5	0.159
2-Methylpentane	2	0.064	Isopropylbenzene	2	0.064
3-Methylpentane	1	0.032	1,2,3-Trimethylbenzene	33	1.050
Cyclopentane	0	0.000	1,2,4-Trimethylbenzene	74	2.353
Methyl cyclopentane	1	0.032	1,3,5-Trimethylbenzene	28	0.891
2,3-Dimethylpentane	1	0.032	Styrene	ND	ND
n-Hexane	4	0.127	Toluene	7	0.223
3-Methylhexane	2	0.064	p-Xylene &/or m-Xylene	28	0.891
Cyclohexane	0	0.000	o-Xylene	14	0.445
Methylcyclohexane	5	0.159	**Total Aromatic HCs**	191	**6.074**
2,2,4-Trimethylpentane	ND	ND			
n-Heptane	7	0.223			
n-Octane	16	0.509			
n-Nonane	63	2.004			
n-Decane	252	8.015			
n-Undecane	660	20.990			
n-Dodecane	685	21.785			
n-Tridecane	404	12.849			
n-Tetradecane	269	8.555			
TOTAL Aliphatic HCs	2377	**75.597**			

Polycyclic Aromatic Hydrocarbons

PAH	Total Mass of PAHs collected (filter + tube) µg	Total PAH Concentration in headspace (mg/m³)
Naphthalene	170.4	1.409
Biphenyl	92.7	0.767
Acenaphthylene	11.9	0.098
Acenaphthene	52.7	0.436
Fluorene	56.8	0.470
Phenathrene	19.6	0.162
Anthracene	2.2	0.018
Fluorathene	0.1	0.001
Pyrene	1.2	0.010
Benz(a)anthracene	0.1	0.001
Chrysene	0.2	0.002
Benzo(b)fluoranthrene	ND	ND
Benzo(k)fluoranthrene	ND	ND
Benzo(a)pyrene	ND	ND
Indeno(1,2,3-cd) pyrene	ND	ND
Bibenz(a,h)anthracene	ND	ND
Benzo(g,h,i) perylene	ND	ND
TOTAL PAHs	**407.9**	**3.373**

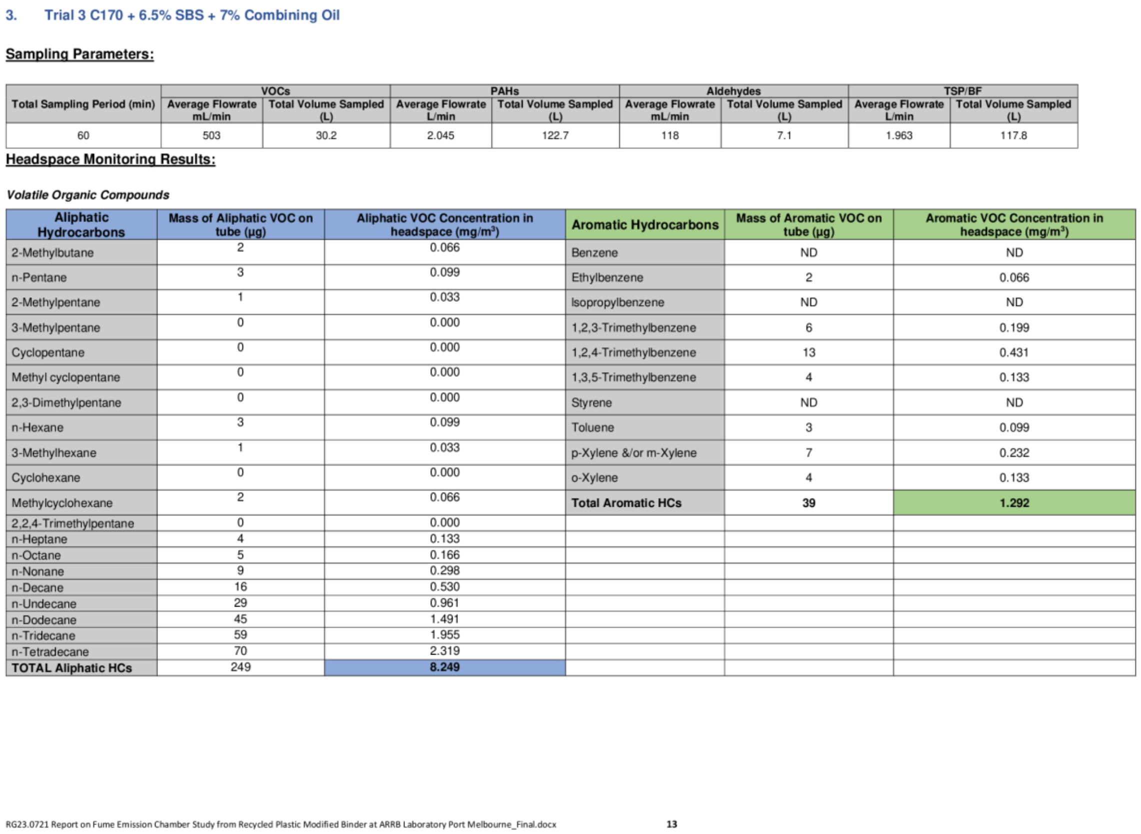
+ Note: some breakthrough of the more volatile PAHs was observed from the front to the rear section of the XAD-2 tube

Aliphatic Aldehydes

Aliphatic Aldehyde Results	Mass of Aliphatic Aldehyde on tube (µg)	Aliphatic Aldehyde Concentration in headspace (mg/m³)
Formaldehyde	1.59	0.21
Acetaldehyde	11.52	1.50
Crotonaldehyde	ND	ND
Valeraldehyde	ND	ND

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

TSP on filter (mg)	TCP Concentration in headspace (mg/m3)	BF on filter(mg)	BF Concentration in headspace(mg/m³)
7.4	**63.3**	6.9	**59.0**



3. Trial 3 C170 + 6.5% SBS + 7% Combining Oil

Sampling Parameters:

Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
	Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
60	503	30.2	2.045	122.7	118	7.1	1.963	117.8

Headspace Monitoring Results:

Volatile Organic Compounds

Aliphatic Hydrocarbons	Mass of Aliphatic VOC on tube (µg)	Aliphatic VOC Concentration in headspace (mg/m³)	Aromatic Hydrocarbons	Mass of Aromatic VOC on tube (µg)	Aromatic VOC Concentration in headspace (mg/m³)
2-Methylbutane	2	0.066	Benzene	ND	ND
n-Pentane	3	0.099	Ethylbenzene	2	0.066
2-Methylpentane	1	0.033	Isopropylbenzene	ND	ND
3-Methylpentane	0	0.000	1,2,3-Trimethylbenzene	6	0.199
Cyclopentane	0	0.000	1,2,4-Trimethylbenzene	13	0.431
Methyl cyclopentane	0	0.000	1,3,5-Trimethylbenzene	4	0.133
2,3-Dimethylpentane	0	0.000	Styrene	ND	ND
n-Hexane	3	0.099	Toluene	3	0.099
3-Methylhexane	1	0.033	p-Xylene &/or m-Xylene	7	0.232
Cyclohexane	0	0.000	o-Xylene	4	0.133
Methylcyclohexane	2	0.066	**Total Aromatic HCs**	**39**	**1.292**
2,2,4-Trimethylpentane	0	0.000			
n-Heptane	4	0.133			
n-Octane	5	0.166			
n-Nonane	9	0.298			
n-Decane	16	0.530			
n-Undecane	29	0.961			
n-Dodecane	45	1.491			
n-Tridecane	59	1.955			
n-Tetradecane	70	2.319			
TOTAL Aliphatic HCs	249	**8.249**			

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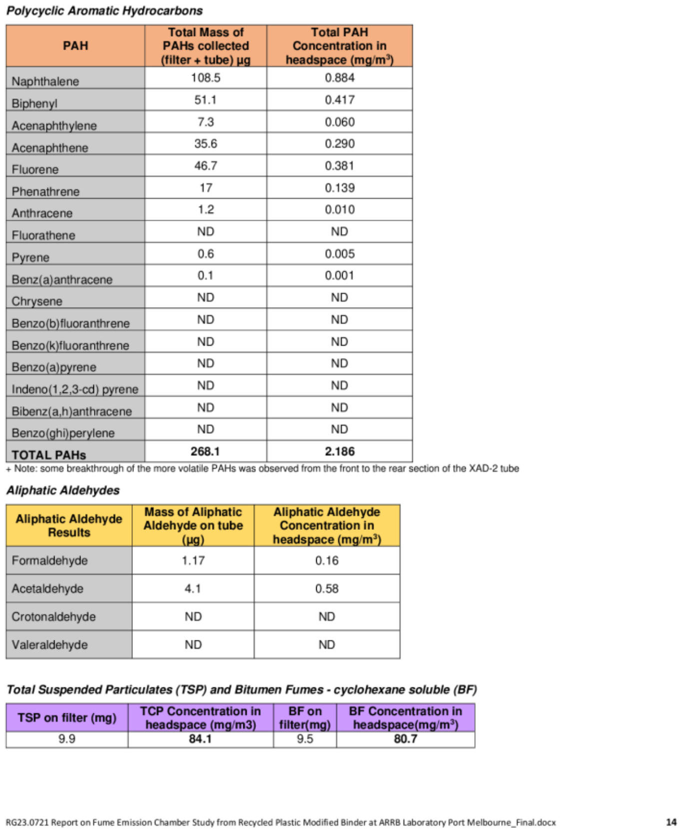

Polycyclic Aromatic Hydrocarbons

PAH	Total Mass of PAHs collected (filter + tube) µg	Total PAH Concentration in headspace (mg/m³)
Naphthalene	108.5	0.884
Biphenyl	51.1	0.417
Acenaphthylene	7.3	0.060
Acenaphthene	35.6	0.290
Fluorene	46.7	0.381
Phenathrene	17	0.139
Anthracene	1.2	0.010
Fluorathene	ND	ND
Pyrene	0.6	0.005
Benz(a)anthracene	0.1	0.001
Chrysene	ND	ND
Benzo(b)fluoranthrene	ND	ND
Benzo(k)fluoranthrene	ND	ND
Benzo(a)pyrene	ND	ND
Indeno(1,2,3-cd) pyrene	ND	ND
Bibenz(a,h)anthracene	ND	ND
Benzo(ghi)perylene	ND	ND
TOTAL PAHs	**268.1**	**2.186**

+ Note: some breakthrough of the more volatile PAHs was observed from the front to the rear section of the XAD-2 tube

Aliphatic Aldehydes

Aliphatic Aldehyde Results	Mass of Aliphatic Aldehyde on tube (µg)	Aliphatic Aldehyde Concentration in headspace (mg/m³)
Formaldehyde	1.17	0.16
Acetaldehyde	4.1	0.58
Crotonaldehyde	ND	ND
Valeraldehyde	ND	ND

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

TSP on filter (mg)	TCP Concentration in headspace (mg/m3)	BF on filter(mg)	BF Concentration in headspace(mg/m³)
9.9	**84.1**	9.5	**80.7**

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4. Trial 4 C170 + 10% LDPE

Sampling Parameters:

Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
	Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
60	514	30.8	2.021	121.3	117	7.0	1.955	117.3

Headspace Monitoring Results:

Volatile Organic Compounds

Aliphatic Hydrocarbons	Mass of Aliphatic VOC on tube (µg)	Aliphatic VOC Concentration in headspace (mg/m³)	Aromatic Hydrocarbons	Mass of Aromatic VOC on tube (µg)	Aromatic VOC Concentration in headspace (mg/m³)
2-Methylbutane	3	0.097	Benzene	6	0.195
n-Pentane	7	0.227	Ethylbenzene	5	0.162
2-Methylpentane	3	0.097	Isopropylbenzene	1	0.032
3-Methylpentane	2	0.065	1,2,3-Trimethylbenzene	18	0.584
Cyclopentane	1	0.032	1,2,4-Trimethylbenzene	43	1.395
Methyl cyclopentane	2	0.065	1,3,5-Trimethylbenzene	14	0.454
2,3-Dimethylpentane	2	0.065	Styrene	ND	ND
n-Hexane	8	0.260	Toluene	8	0.260
3-Methylhexane	3	0.097	p-Xylene &/or m-Xylene	23	0.746
Cyclohexane	ND	ND	o-Xylene	11	0.357
Methylcyclohexane	4	0.130	**Total Aromatic HCs**	**129**	**4.185**
2,2,4-Trimethylpentane	ND	ND			
n-Heptane	10	0.324			
n-Octane	15	0.487			
n-Nonane	36	1.168			
n-Decane	97	3.146			
n-Undecane	181	5.871			
n-Dodecane	182	5.904			
n-Tridecane	141	4.574			
n-Tetradecane	134	4.347			
TOTAL Aliphatic HCs	**831**	**26.956**			

Polycyclic Aromatic Hydrocarbons

PAH	Total Mass of PAHs collected (filter + tube) µg	Total PAH Concentration in headspace (mg/m³)
Naphthalene	157	1.295
Biphenyl	56.5	0.466
Acenaphthylene	7	0.058
Acenaphthene	31.7	0.261
Fluorene	34.6	0.285
Phenathrene	11.4	0.094
Anthracene	1.2	0.010
Fluorathene	ND	ND
Pyrene	0.5	0.004
Benz(a)anthracene	ND	ND
Chrysene	0.2	0.002
Benzo(b)fluoranthrene	ND	ND
Benzo(k)fluoranthrene	ND	ND
Benzo(a)pyrene	ND	ND
Indeno(1,2,3-cd) pyrene	ND	ND
Bibenz(a,h)anthracene	ND	ND
Benzo(ghi)perylene	ND	ND
TOTAL PAHs	**300.1**	**2.475**

+ Note: some breakthrough of the more volatile PAHs was observed from the front to the rear section of the XAD-2 tube

Aliphatic Aldehydes

Aliphatic Aldehyde Results	Mass of Aliphatic Aldehyde on tube (µg)	Aliphatic Aldehyde Concentration in headspace (mg/m³)
Formaldehyde	2.63	0.38
Acetaldehyde	10.02	1.43
Crotonaldehyde	ND	ND
Valeraldehyde	ND	ND

Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

TSP on filter (mg)	TCP Concentration in headspace (mg/m3)	BF on filter(mg)	BF Concentration in headspace(mg/m³)
4.9	**41.8**	4.3	**36.7**

5. Trial 5 C170 + 10% HDPE/PP

Sampling Parameters:

Total Sampling Period (min)	VOCs		PAHs		Aldehydes		TSP/BF	
	Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)	Average Flowrate mL/min	Total Volume Sampled (L)	Average Flowrate L/min	Total Volume Sampled (L)
60	516	31.0	2.016	120.9	129	7.7	1.955	117.3

Headspace Monitoring Results:

Volatile Organic Compounds

Aliphatic Hydrocarbons	Mass of Aliphatic VOC on tube (µg)	Aliphatic VOC Concentration in headspace (mg/m³)	Aromatic Hydrocarbons	Mass of Aromatic VOC on tube (µg)	Aromatic VOC Concentration in headspace (mg/m³)
2-Methylbutane	4	0.129	Benzene	2	0.065
n-Pentane	7	0.226	Ethylbenzene	9	0.291
2-Methylpentane	4	0.129	Isopropylbenzene	3	0.097
3-Methylpentane	2	0.065	1,2,3-Trimethylbenzene	34	1.098
Cyclopentane	1	0.032	1,2,4-Trimethylbenzene	81	2.615
Methyl cyclopentane	2	0.065	1,3,5-Trimethylbenzene	31	1.001
2,3-Dimethylpentane	2	0.065	Styrene	ND	ND
n-Hexane	8	0.258	Toluene	11	0.355
3-Methylhexane	4	0.129	p-Xylene &/or m-Xylene	44	1.421
Cyclohexane	ND	ND	o-Xylene	20	0.646
Methylcyclohexane	7	0.226	**Total Aromatic HCs**	**235**	**7.587**
2,2,4-Trimethylpentane	0	0.000			
n-Heptane	12	0.387			
n-Octane	26	0.839			
n-Nonane	88	2.841			
n-Decane	277	8.944			
n-Undecane	501	16.176			
n-Dodecane	444	14.336			
n-Tridecane	279	9.008			
n-Tetradecane	257	8.298			
TOTAL Aliphatic HCs	**1925**	**62.153**			

Polycyclic Aromatic Hydrocarbons

PAH	Total Mass of PAHs collected (filter + tube) µg	Total PAH Concentration in headspace (mg/m³)
Naphthalene	131.4	1.087
Biphenyl	61.2	0.506
Acenaphthylene	10	0.083
Acenaphthene	42.1	0.348
Fluorene	54.8	0.453
Phenathrene	16.9	0.140
Anthracene	1.6	0.013
Fluorathene	ND	ND
Pyrene	0.8	0.007
Benz(a)anthracene	0.1	0.001
Chrysene	0.3	0.002
Benzo(b)fluoranthrene	ND	ND
Benzo(k)fluoranthrene	ND	ND
Benzo(a)pyrene	ND	ND
Indeno(1,2,3-cd) pyrene	ND	ND
Bibenz(a,h)anthracene	ND	ND
Benzo(ghi)perylene	ND	ND
TOTAL PAHs	**319.2**	**2.640**

+ Note: some breakthrough of the more volatile PAHs was observed from the front to the rear section of the XAD-2 tube

Aliphatic Aldehydes

Aliphatic Aldehyde Results	Mass of Aliphatic Aldehyde on tube (µg)	Aliphatic Aldehyde Concentration in headspace (mg/m³)
Formaldehyde	1.88	0.24
Acetaldehyde	7.83	1.01
Crotonaldehyde	ND	ND
Valeraldehyde	ND	ND

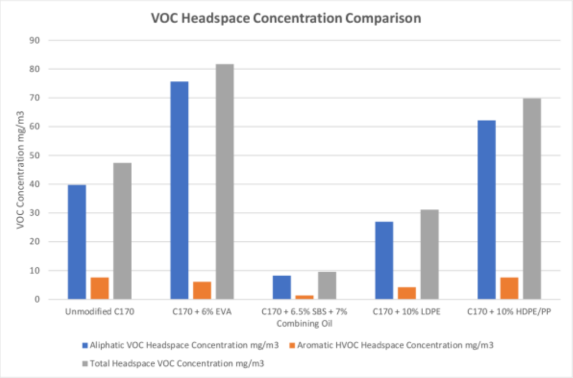
Total Suspended Particulates (TSP) and Bitumen Fumes - cyclohexane soluble (BF)

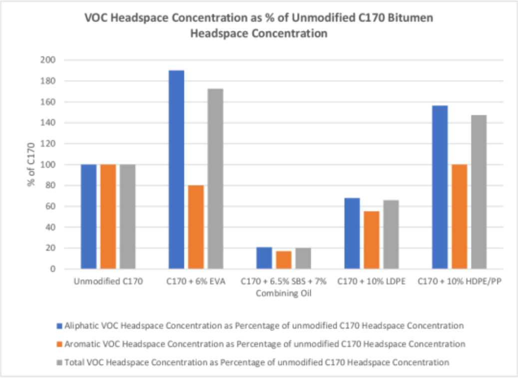
TSP on filter (mg)	TCP Concentration in headspace (mg/m3)	BF on filter(mg)	BF Concentration in headspace(mg/m³)
8.3	**70.8**	7.5	**64.0**

Discussion of Results

VOC Headspace Concentration Result Comparison

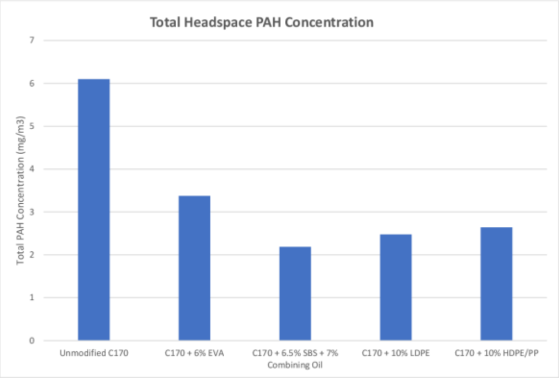
Bitumen Blend	Aliphatic VOC Headspace Concentration mg/m³	Aromatic HVOC Headspace Concentration mg/m³	Total Headspace VOC Concentration mg/m³	Aliphatic VOC Headspace Concentration as Percentage of unmodified C170 Headspace Concentration	Aromatic VOC Headspace Concentration as Percentage of unmodified C170 Headspace Concentration	Total VOC Headspace Concentration as Percentage of unmodified C170 Headspace Concentration
Unmodified C170	39.760	7.592	47.352	100	100.000	100.000
C170 + 6% EVA	75.597	6.074	81.671	190.1	80.0	172.5
C170 + 6.5% SBS + 7% Combining Oil	8.249	1.292	9.541	20.7	17.0	20.1
C170 + 10% LDPE	26.956	4.185	31.141	67.8	55.1	65.8
C170 + 10% HDPE/PP	62.153	7.587	69.740	156.3	99.9	147.3

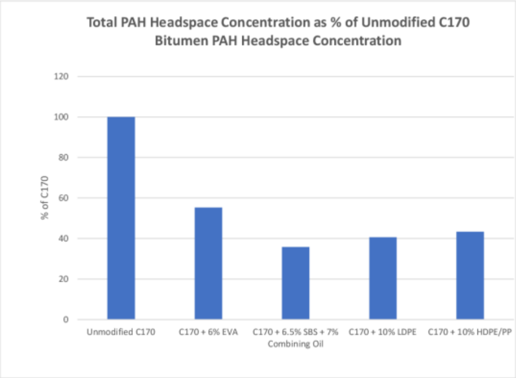




PAH Headspace Concentration Result Comparison

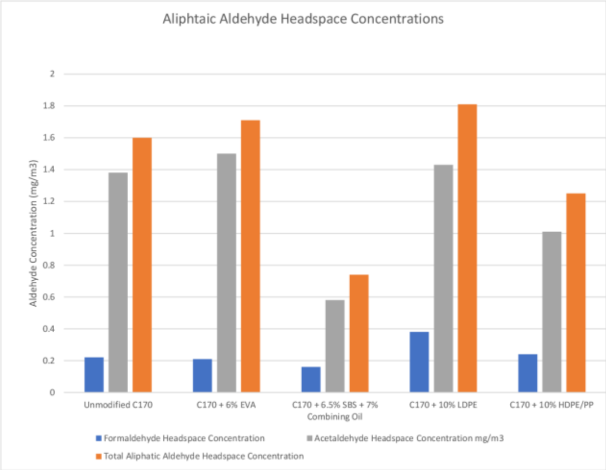
Bitumen Blend	Total Headspace PAH Concentration mg/m³	Total PAH Headspace as Percentage of Unmodified C170 Headspace Concentration (%)
Unmodified C170	6.098	100.0
C170 + 6% EVA	3.373	55.3
C170 + 6.5% SBS + 7% Combining Oil	2.186	35.8
C170 + 10% LDPE	2.475	40.6
C170 + 10% HDPE/PP	2.64	43.3

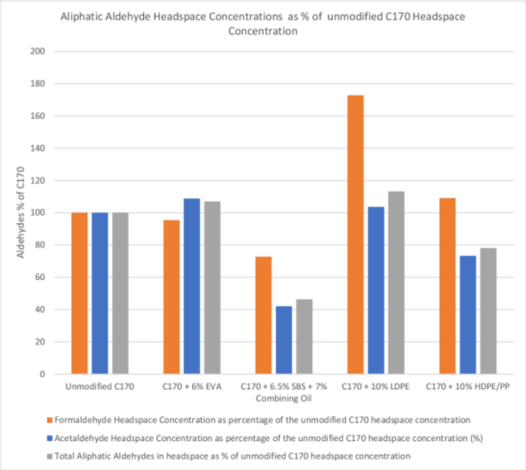




Aliphatic Aldehyde Headspace Concentration Result Comparison

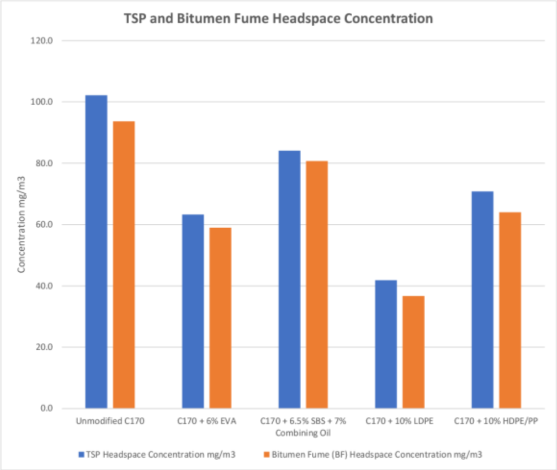
Bitumen Blend	Formaldehyde Headspace Concentration mg/m^3	Acetaldehyde Headspace Concentration mg/m^3	Total Aliphatic Aldehyde Headspace Concentration mg/m^3	Formaldehyde Headspace Concentration as percentage of the unmodified C170 headspace concentration (%)	Acetaldehyde Headspace Concentration as percentage of the unmodified C170 headspace concentration (%)	Total Aliphatic Aldehyde Headspace Concentration as percentage of the unmodified C170 headspace concentration (%)
Unmodified C170	0.22	1.38	1.60	100.00	100.00	100.00
C170 + 6% EVA	0.21	1.50	1.71	95.45	108.70	106.88
C170 + 6.5% SBS + 7% Combining Oil	0.16	0.58	0.74	72.73	42.03	46.25
C170 + 10% LDPE	0.38	1.43	1.81	172.73	103.62	113.13
C170 + 10% HDPE/PP	0.24	1.01	1.25	109.09	73.19	78.13

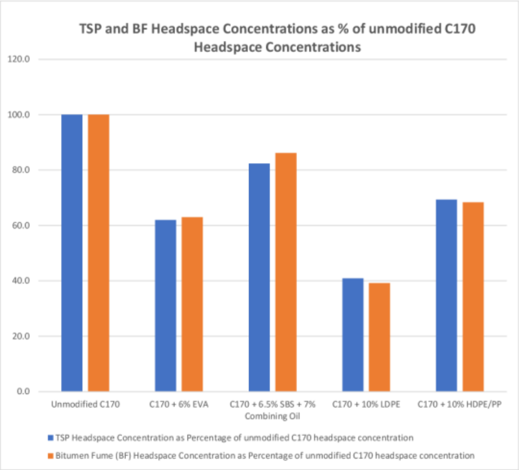




TSP and BF Headspace Concentration Result Comparison

Bitumen Blend	TSP Headspace Concentration mg/m^3	Bitumen Fume (BF) Headspace Concentration mg/m^3	TSP Headspace Concentration as Percentage of unmodified C170 headspace concentration (%)	Bitumen Fume (BF) Headspace Concentration as Percentage of unmodified C170 headspace concentration (%)
Unmodified C170	102.1	93.6	100.0	100.0
C170 + 6% EVA	63.3	59.0	62.0	63.0
C170 + 6.5% SBS + 7% Combining Oil	84.1	80.7	82.3	86.2
C170 + 10% LDPE	41.8	36.7	40.9	39.2
C170 + 10% HDPE/PP	70.8	64.0	69.3	68.3





Discussion

VOCs

In this project, we found that the total concentration of VOCs in the headspaces for the C170 + 6% EVA and the C170 + 10% HDPE/PP were significantly higher than for unmodified bitumen (between 147% and 172% higher), the C170 + 6.5% SBS + 7% combining oil and C170 + 10% LDPE blends. These higher results were exclusively due to the higher concentrations of aliphatic hydrocarbons in the C10 to C14 range. It is beyond the scope of this project to identify the source(s) of the higher aliphatic hydrocarbon emissions from the C170 + 6% EVA and C170 + 10% HDPE/PP.
The levels of aromatic VOC/petroleum hydrocarbons were found to be highest in the headspace of the unmodified bitumen sample with a similar concentration being measured in the headspace of the C170 + 10% HDPE bitumen mix. The level of aromatic hydrocarbons in the C170 + 6.5% SBS + 7% combining oil bitumen blend was found to be significantly lower than the other blends at only 17% of that found in the unmodified C170 bitumen headspace. Observations at the time of the trials noted that the viscosity of the C170 + 6.5% SBS + 7% combining oil appeared to be significantly higher than the other blends. This higher viscosity may reduce the emission of aromatic hydrocarbons from the surface of the molten bitumen. The effect of viscosity on total VOC and PAH emissions from polymer modified bitumens was observed in a paper presented by Porot et al. titled *Laboratory evaluation of emissions from Polymer modified Bitumen* (https://www.researchgate.net/publication/343105816_Laboratory_evaluation_of_emissions_from_Polymer_modified_Bitumen).

PAHs

The concentration of PAHs in the headspace of the unmodified C170 was found to be significantly higher than for all of the bitumen/recycled plastic blends. The lowest PAH headspace concentration was measured for the C170 + 6.5% SBS + 7% combining oil bitumen blend at approximately 36% of the unmodified C170 bitumen whilst the highest headspace PAH concentration for the bitumen/recycled blends was found to be for the C170 + 6% EVA blend. Naphthalene, biphenyl, acenaphthene and fluorene were the major components of the total PAH headspace concentrations for all blends. No benzo(a)pyrene (highest potency carcinogen) was detected in any of the headspace samples. As previously discussed, the lower emissions of PAHs from the bitumen/recycled plastic blends may be related to the higher viscosity of the blends compared with unmodified C170 grade bitumen.

Aliphatic Aldehydes

In this project, we found that the concentration of formaldehyde in the headspace of the C170 + 10% LDPE blend was higher than for the other blends with the levels being approximately 173% of that measured for the unmodified C170 sample. The lowest level of formaldehyde concentration in the headspace was found to be for the C170 + 6.5% SBS + 7% combining oil binder at approximately 73% of that in the unmodified C170 headspace sample and 42% of that measured in the C170 + 10% LDPE. The headspace concentrations of acetaldehyde for the C170 + 6% EVA and C170 + 10% HDPE/PP blends were found to be similar to that of the unmodified C170 bitumen headspace, whilst the levels of acetaldehyde in the C170 + 6.5% SBS + 7% combining oil bitumen blend was 42% of that in the headspace of the unmodified C170 bitumen sample and for the C170 + 10% HDPE/PP blend 73% unmodified C170 bitumen sample.

TSP and BF

The highest concentration of TSP was detected in the headspace of the unmodified C170 bitumen sample whilst the TSP levels for the polymer blends were between 41% (C170 + 10% LDPE) and 69% (C170 + 6.5% SBS + 7% combining oil) of the unmodified C170 bitumen headspace concentration. Similarly, the concentration of BF in the headspace of the unmodified C170 sample was found to be the highest when compared with the C170/recycled plastic blends and followed the same pattern as with the TSP results at between 39% (C170 + 10% LDPE) and 68% (C170 + 6.5% SBS + 7% combining oil).

Conclusion

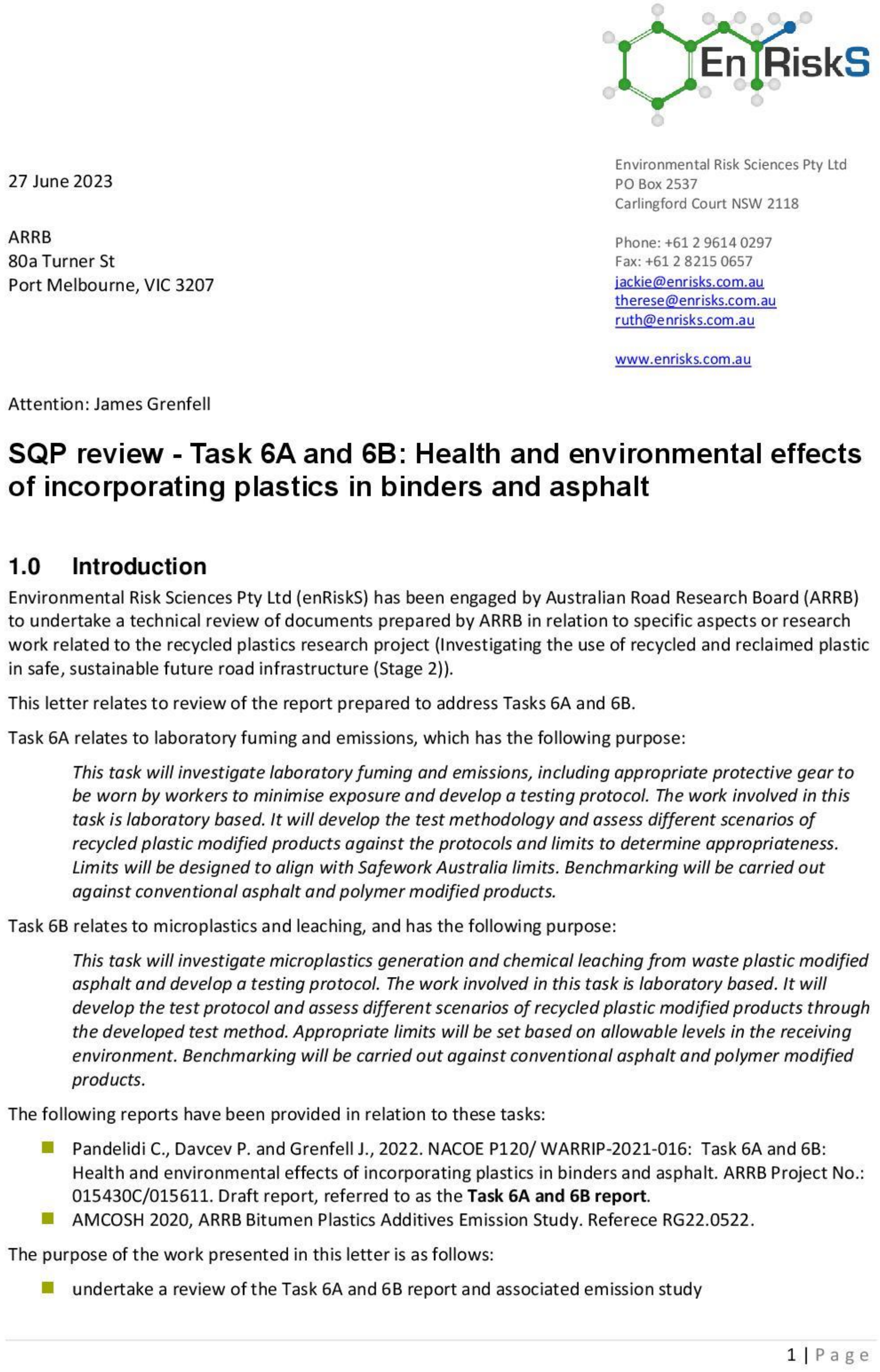
Based on the results of headspace fume emission sampling in an enclosed fume emission generation chamber of various C170 grade bitumen/recycled plastic blends at 180°C, conducted in this project we found the following:

- The levels of aliphatic hydrocarbons in the C10-C14 range were higher in the headspaces of the C170 + 6% EVA and C170 +10% HDPE/PP blends than that in the unmodified C170 bitumen, C170 + 6.5% SBS + 7% combining oil and C170 + 10% LDPE bitumen/recycled plastic headspace;
- The levels of aromatic hydrocarbons were lower in the headspaces of all of the bitumen/recycled plastics blends than that in the unmodified C170 bitumen headspace;
- The levels of total VOCs in the headspaces of the C170 + 6% EVA and C170 +10% HDPE/PP blends was found to be higher than for the other blends and unmodified bitumen, but this was entirely related to the higher levels of aliphatic hydrocarbons in the C10-C14 range;
- The concentrations of PAHs were lower in the headspaces of all of the bitumen/recycled plastics blends than that in the unmodified C170 bitumen headspace;
- The C170 + 10% LDPE blend had a higher formaldehyde (and hence the total aliphatic aldehyde) emission into the headspace than the headspaces of the other blends and the unmodified C170 bitumen;
- Unmodified C170 bitumen fume emission headspace concentrations of TSP and BF were significantly higher than for all of the bitumen/recycled plastics blends.

Based on the limited findings of this study of fume emissions in an enclosed fume emission generation chamber, the emissions of total VOCs and in particular long-chain aliphatic petroleum hydrocarbons in the C10-C14 is higher for C170 + 6% EVA and C170 + 10% HDPE/PP blends than for unmodified C170 bitumen or other bitumen/ plastic blends. Additionally, the emission of formaldehyde from C170 + 6% EVA blends may be higher than for unmodified C170 bitumen or other bitumen/ plastic blends.

The PAH, TSP and BF emissions from unmodified C170 bitumen in the enclosed fume emission generation chamber appear to be significantly higher than for all of the plastic modified binder bitumen samples tested.

Appendix C Suitably Qualified Professional Report



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27 June 2023

ARRB
80a Turner St
Port Melbourne, VIC 3207

Attention: James Grenfell

SQP review - Task 6A and 6B: Health and environmental effects of incorporating plastics in binders and asphalt

1.0 Introduction

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by Australian Road Research Board (ARRB) to undertake a technical review of documents prepared by ARRB in relation to specific aspects or research work related to the recycled plastics research project (Investigating the use of recycled and reclaimed plastic in safe, sustainable future road infrastructure (Stage 2)).

This letter relates to review of the report prepared to address Tasks 6A and 6B.

Task 6A relates to laboratory fuming and emissions, which has the following purpose:

> *This task will investigate laboratory fuming and emissions, including appropriate protective gear to be worn by workers to minimise exposure and develop a testing protocol. The work involved in this task is laboratory based. It will develop the test methodology and assess different scenarios of recycled plastic modified products against the protocols and limits to determine appropriateness. Limits will be designed to align with Safework Australia limits. Benchmarking will be carried out against conventional asphalt and polymer modified products.*

Task 6B relates to microplastics and leaching, and has the following purpose:

> *This task will investigate microplastics generation and chemical leaching from waste plastic modified asphalt and develop a testing protocol. The work involved in this task is laboratory based. It will develop the test protocol and assess different scenarios of recycled plastic modified products through the developed test method. Appropriate limits will be set based on allowable levels in the receiving environment. Benchmarking will be carried out against conventional asphalt and polymer modified products.*

The following reports have been provided in relation to these tasks:

- Pandelidi C., Davcev P. and Grenfell J., 2022. NACOE P120/ WARRIP-2021-016: Task 6A and 6B: Health and environmental effects of incorporating plastics in binders and asphalt. ARRB Project No.: 015430C/015611. Draft report, referred to as the **Task 6A and 6B report**.
- AMCOSH 2020, ARRB Bitumen Plastics Additives Emission Study. Referece RG22.0522.

The purpose of the work presented in this letter is as follows:

- undertake a review of the Task 6A and 6B report and associated emission study

- provide advice on any concerns over the findings presented in relation to human health or the environment
- comment on the practicality of any additional testing that may be required as part of any field monitoring program.

2.0 Qualification of author/SQP

This review has been undertaken by Dr Jackie Wright, Director of enRiskS. **Appendix A** presents a curriculum vitae for Dr Jackie Wright which demonstrates that she meets the requirements of a Suitably Qualified Professional (SQP) for the assessment of harm to human health and the environment.

3.0 Review comments

3.1 General

The Task 6A and 6B report was prepared for the Department of Transport and Main Roads Queensland (TMR), Main Roads Western Australia (MRWA) and the Australian Road Research Board (ARRB), under both the NACoE and WARRIP agreements. The focus of the report relates to the use of recycled plastic (RP) in binders and asphalt. More specifically the report relates to laboratory assessment of fuming and emissions during binder blending and asphalt mixing, the potential generation of microplastics and chemicals in leachate derived from asphalt and bitumen containing recycled plastics.

3.2 Task 6A

This task relates to fuming and emissions from the use of plastics in binder and bitumen. The study presented compares outcomes using the same methods for fumes and emissions derived from binder and bitumen with no additives, with SBS and EVA additives (already approved and used) and the addition of comingled plastic. The bitumen testing included comingled plastic mixed using both a wet and dry method.

The approach adopted for testing of emissions is appropriate and consistent for all materials. The results present in the graphs (for example for total aliphatics and aromatics) are limited by the analytical limit of reporting. The graphs should indicate the samples that are <LOR. Many of the emissions were just not detected. In addition, it would be helpful to include commentary about individual VOCs detected and comparison with the workplace exposure standard (as is included in the AMCOSH report).

Comments:

It is agreed that the results presented indicate low concentrations of chemicals of potential concern in air from binders and bitumen, with no significant increase in concentrations with the addition of comingled plastics (noting there are some chemicals where concentrations are lower for these materials). The PPE requirement for binders and bitumen also apply to plastic modified binders and bitumen.

Given the very low results obtained in the laboratory, and the lack of any data that supports any significant increase in fuming and emissions for workers using binders and bitumen with comingled plastic, it is worth querying if there is a need to do extensive monitoring. Some additional field monitoring would be relevant to confirm the outcome of the laboratory tests, but the scope could be limited unless the field trial results show something different.

3.3 Task 6B

3.3.1 General

This task relates to the testing for the generation of contaminants in leachate and microplastics. The study was conducted by ARRB using in-house developed methods. The testing involved binders and pavement slabs made with no additives, SBS and EVA additives (already approved and used) and the addition of comingles plastics. All slabs used in the testing were prepared using C320 bitumen.

3.3.2 Leach testing

Leach testing was conducted using a method proposed by White (2019). The method uses 2.5 g of the material in 50 mL deionised water and air forced heating at 40 °C for 18 hours. A 4 µm mesh filter was used to filter the sample prior to analysis. Analysis was undertaken using GCMS.

The results of the leach testing indicated that PAHs, BPA, styrene, hydrocarbons or phthalates are not detectable in the leachate. The results are consistent with those from White (White 2019).

Comments:

This method differs from the more traditional and standard leachate testing used for environmental assessments, ASLP (Australian Standard Leach Procedure as specified in Australian Standards 4439.2 and 4439.3). The discussion (Section 4.1.4 of the Task 6A and 6B report) references a method from Thayumanavan et al. (2003), where the short-term methodology is more similar to an ASLP leach testing. In general, the method involves vigorously shaking a sample in distilled water (four parts liquid) at 24 °C for 24 hours for short-term leaching and 168 hours for long-term leaching. While such methods are more commonly used for assessing environmental leaching, the validity of the results in terms of representing leaching under environmental conditions is less clear and the subject of ongoing debate (DER 2015).

It would be helpful to include some additional discussion on the methodology adopted by White (2019) as to the representativeness of environmental conditions (over a long period of time). Comparison testing with either a standard ASLP test, or the method from Thayumanavan et al. (2003) could be undertaken to determine if these more vigorous shaking methods result in different outcomes. It would also be helpful to include some additional analysis of the materials following wear and tear to see if weathering or aging/prolonged use changes the potential for leaching.

3.3.3 Microplastics

The generation of microplastics was tested using a method that involved spraying with water, abrading the surface for 120 minutes and collection of water from the material. The water was evaporated and the solid matter remaining collected, a solvent added to dissolve the bitumen particles (noting the method affects SBS polymers, but not EVA and comingled plastic), and the solution filtered through a 0.45 µm mesh filter (a number of times to remove the bitumen), evaporated, glycerine added to separate plastics (which floated and could be collected) and further filtered through a 4 µm mesh filter. Testing involved gravimetric analysis, thermogravimetric analysis (TGA)and optical microscopy.

The results indicated the following:

- most of the mass of the abraded samples comprised aggregates
- the incorporation of comingled plastics in asphalt through the dry process may be more susceptible to the generation of microplastics
- more bitumen was released following abrasion of slabs made with polymer modified bitumen compared with unmodified bitumen.

TGA is considered to provide a more accurate method for the quantification of microplastics from such materials, noting that gravimetric data was found to have a number of limitations that limits accuracy and confidence in the results.

Comments:

The methodology adopted for evaluating the potential generation of microplastics is reasonable, and has been applied consistently on all materials tested. For the assessment of microplastics, there are no specific guidelines available, hence it is important to be able to understand whether the comingled plastic modified bitumen results in an increase in the total amount of microplastics release to the environment.

It may be worth considering if there is a way of also testing more weathered materials, to determine if long-term use affects the potential generation of microplastics.

4.0 Limitations

Environmental Risk Sciences has prepared this report for the use of the Australian Road Research Board (ARRB), Main Roads Western Australia (MRWA) and the Queensland Department of Transport and Main Roads (TMR) in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report.

It is prepared in accordance with the scope of work and for the purpose outlined in the **Section 1** of this report.

The methodology adopted and sources of information used are outlined in this report. Environmental Risk Sciences has made no independent verification of this information beyond the agreed scope of works and assumes no responsibility for any inaccuracies or omissions. No indications were found that information provided for use in this assessment was false.

This report was prepared in July 2022 and finalised in June 2023. Environmental Risk Sciences disclaims responsibility for any changes that may have occurred after this time.

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This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

5.0 Closure

If you require any additional information or if you wish to discuss any aspect of this review, please do not hesitate to contact the undersigned on (02) 9614 0297.

Yours sincerely,

Dr Jackie Wright (Fellow ACTRA)
Principal/Director
Environmental Risk Sciences Pty Ltd

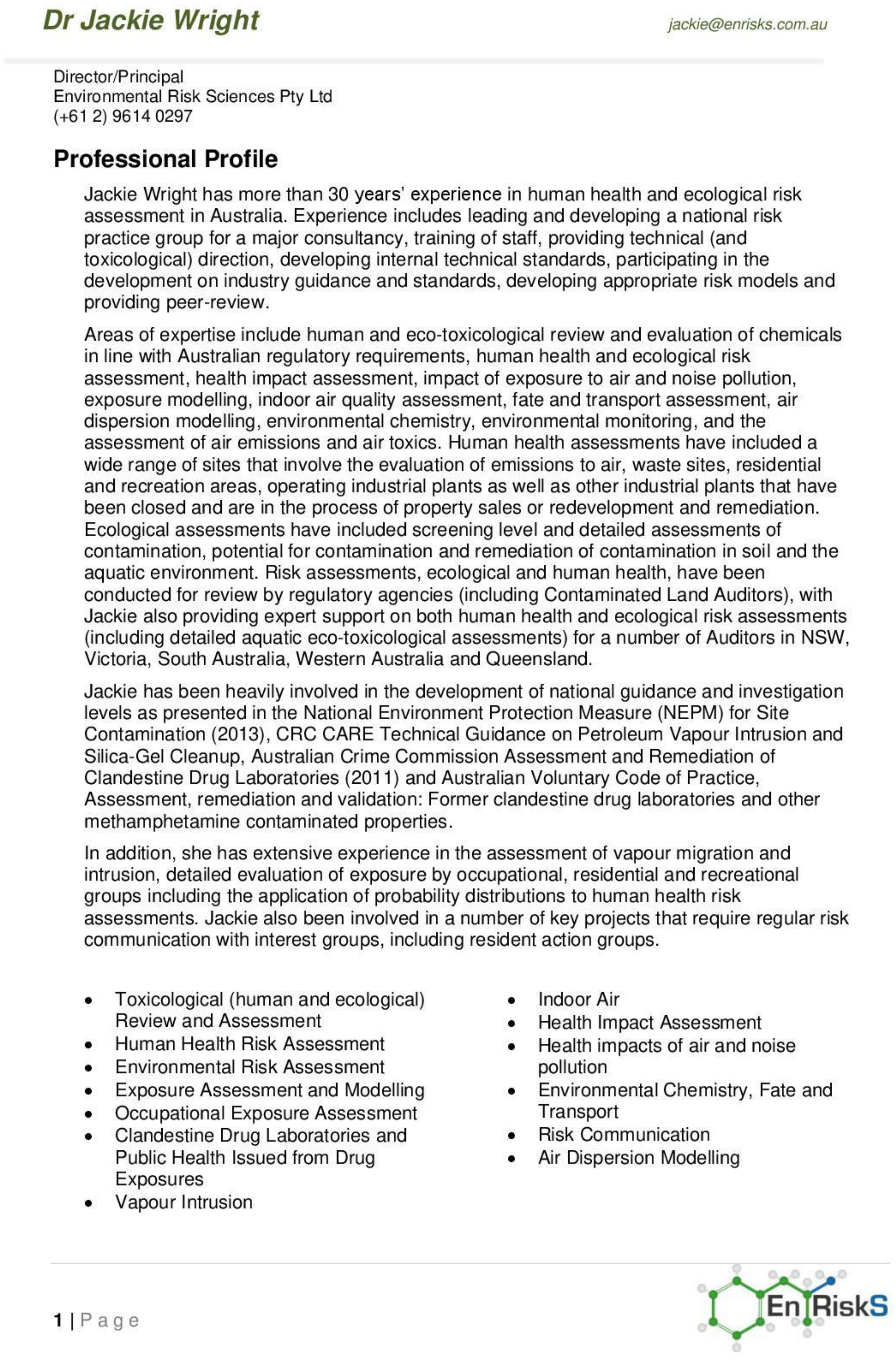
References

DER 2015, *Background paper on the use of leaching tests for assessing the disposal and re-use of waste-derived materials*, Government of Western Australia, Department of Environment Regulation, Perth. <https://www.der.wa.gov.au/images/documents/our-work/consultation/wdm/background-paper-use-of-leaching-tests.pdf>.

Thayumanavan, P, Nelson, PO, Azizian, MF, Williamson, KJ & Lundy, JR 2003, 'Environmental impact of highway construction and repair materials on surface water and groundwater: Detailed evaluation of waste-amended highway materials', *Transportation Research Record Journal of the Transportation Research Board,* vol. 1743, no. 1, pp. 25-32.

White, G 2019, 'Evaluating recycled waste plastic modification and extension of bituminous binder for asphalt', *18th Annual International Conference on Pavement Engineering, Asphalt Technology and Infrastructure*. viewed 10 May 2022,

Attachment A: CV for Dr Jackie Wright



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Professional Profile

Jackie Wright has more than 30 years' experience in human health and ecological risk assessment in Australia. Experience includes leading and developing a national risk practice group for a major consultancy, training of staff, providing technical (and toxicological) direction, developing internal technical standards, participating in the development on industry guidance and standards, developing appropriate risk models and providing peer-review.

Areas of expertise include human and eco-toxicological review and evaluation of chemicals in line with Australian regulatory requirements, human health and ecological risk assessment, health impact assessment, impact of exposure to air and noise pollution, exposure modelling, indoor air quality assessment, fate and transport assessment, air dispersion modelling, environmental chemistry, environmental monitoring, and the assessment of air emissions and air toxics. Human health assessments have included a wide range of sites that involve the evaluation of emissions to air, waste sites, residential and recreation areas, operating industrial plants as well as other industrial plants that have been closed and are in the process of property sales or redevelopment and remediation. Ecological assessments have included screening level and detailed assessments of contamination, potential for contamination and remediation of contamination in soil and the aquatic environment. Risk assessments, ecological and human health, have been conducted for review by regulatory agencies (including Contaminated Land Auditors), with Jackie also providing expert support on both human health and ecological risk assessments (including detailed aquatic eco-toxicological assessments) for a number of Auditors in NSW, Victoria, South Australia, Western Australia and Queensland.

Jackie has been heavily involved in the development of national guidance and investigation levels as presented in the National Environment Protection Measure (NEPM) for Site Contamination (2013), CRC CARE Technical Guidance on Petroleum Vapour Intrusion and Silica-Gel Cleanup, Australian Crime Commission Assessment and Remediation of Clandestine Drug Laboratories (2011) and Australian Voluntary Code of Practice, Assessment, remediation and validation: Former clandestine drug laboratories and other methamphetamine contaminated properties.

In addition, she has extensive experience in the assessment of vapour migration and intrusion, detailed evaluation of exposure by occupational, residential and recreational groups including the application of probability distributions to human health risk assessments. Jackie also been involved in a number of key projects that require regular risk communication with interest groups, including resident action groups.

- Toxicological (human and ecological) Review and Assessment
- Human Health Risk Assessment
- Environmental Risk Assessment
- Exposure Assessment and Modelling
- Occupational Exposure Assessment
- Clandestine Drug Laboratories and Public Health Issued from Drug Exposures
- Vapour Intrusion
- Indoor Air
- Health Impact Assessment
- Health impacts of air and noise pollution
- Environmental Chemistry, Fate and Transport
- Risk Communication
- Air Dispersion Modelling

Professional Accomplishments

Toxicology and Risk Assessment

- 2005 to 2023 (ongoing process of development and revision) - Prepared over 50 toxicity summaries for a range of chemicals relevant to the inclusion and assessment of these chemicals within human health and ecological risk assessments in accordance with Australian guidance. Toxicity summaries prepared provide detail on the chemical use, sources, exposures, chemical properties, ecotoxicity (terrestrial and aquatic), environmental fate and transport, health effects, review and identification of appropriate data relevant to acute and chronic exposures by the inhalation, oral and dermal routes, including assessment of carcinogenicity and genotoxicity. Range of compounds assessed includes particulate matter, petroleum compounds, chlorinated compounds, metals and more obscure industry-specific compounds. More specific, detailed review of arsenic dose-response has been undertaken based on current studies.
- 2014-2015 – conducting detailed toxicological review of TCE, particularly in relation to the quantification of inhalation dose-response.
- 2009 to 2013 – provided detailed toxicological review, determination of appropriate dose-response values, and derivation of proposed 2013 NEPM Soil Health Investigation Levels (HILs), including the interim soil gas HILs, and input into the petroleum Health Screening Levels (HSLs). The review included significant update and revision to Schedules B4 and B7 and involved incorporation of all comments from regulators, industry and the public.
- 2009 and ongoing – Detailed review of the toxicity of a range of illicit drugs relevant to the assessment of environmental exposures or public health impacts of exposure to second or third-hand exposures
- 2010 – provided detailed review of toxicological interactions, biomonitoring data and human exposure to metals (and metal mixtures) for a site in Tasmania.
- 2006 to 2023 (and ongoing) - Presentation and collaboration with regulatory bodies in Australia (New South Wales Environmental Protection Authority [EPA], New South Wales Department of Health and Victorian EPA) with regards to the approach adopted and information presented with toxicity summaries (addressing human health and aquatic toxicity where required) for key, high profile assessments.

Exposure and Risk Assessment (Human Health and General Environmental)

- 1992 to 2023 (ongoing) - Project management and evaluation of human health and environmental risks associated with over 350 contaminated sites in all states of Australia utilising national guidance that include NEPM, enHealth, ANZECC and NH&MRC guidance. Sites include operational sites as well as other industrial areas proposed for redevelopment for industrial, recreational or residential use. Most of the sites assessed are associated with petroleum contamination, chlorinated hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and metals. Other sites include those impacted with dioxins, phthalates, PCBs and PFOS/PFOA.
- 1995 to 2023 (ongoing) - Detailed assessment and ongoing evaluation of risks to human health associated with contamination issues derived from the Orica Botany site in Sydney. A number of assessments have been undertaken over a period of 17 years and has involved detailed review of risks to residents (including groundwater extraction and use), workers and recreational users of a large area affected by the discharge of contamination in shallow and deep groundwater to surface water within a drain and an estuary, historically deposited sediments and volatile chlorinated compounds in air. The assessment of risk has been tied closely

with ongoing monitoring with detailed exposure reviews, including the collection of additional data and ongoing review of methods, being undertaken for many key aspects of the project. The process required evaluation within context of the NEPM (1999) and enHealth (2002) guidance with regular liaison with the NSW OEH, NSW Department of Health and independent reviewers.

- 2009 to 2015 - Derivation of national guidelines for the investigation and remediation of clandestine drug laboratories in Australia. The work involved the derivation of investigation levels, protective human health and the environment (terrestrial and aquatic), associated with former clandestine drug laboratories in Australia. Project required identification of key indicator compounds from over 200 base, intermediate and waste products that may be associated with over 20 different drug manufacturing methods. This required consideration of human health and environmental toxicity, behaviour/fate and transport in the environment and manufacturing methods. Guidelines were derived for indoor surface residues, indoor air, outdoor soil and the environment (local waterways and soil) for residential, commercial and recreational areas. The guidelines developed have been published by the Australian Government in April 2011. Further development of state guidelines, such as those from NSW Health have been undertaken to 2015.
- 2019 – Development of Australian Voluntary Code of Practice, Assessment, remediation and validation: Former clandestine drug laboratories and other methamphetamine contaminated properties, as published by Environmental Health Australia. The publication of these guidelines ahs included a range of workshops to share information and better understand issues and data gaps in the management of drug affected properties.
- 2017 to 2023 – Review of a range of issues relating to exposures to illicit drugs by the public and provision of expert advice to understand exposure, toxicity and potential for adverse effects.
- 2010 to 2023 – Detailed evaluation of community exposures and risks to PM10 and PM2.5 derived from urban (combustion) sources as well as crustal (mining) sources. A number of urban projects have been completed, including major road infrastructure projects such as NorthConnex, WestConnex M4 East, WestConnex New M5, WestConnex M4-M5 Link, F6 Stage 1, Western Harbour Tunnel, Beaches Link and Great Western Highway in NSW and West Gate Tunnel and North East Link in Victoria and rail infrastructure projects including the Moorebank Intermodal Terminal and Botany Rail Duplication in NSW and the Suburban Rail Loop East in Victoria. These infrastructure projects have involved the development and researching of appropriate methodologies for the assessment of particulate exposures, with particular focus on community exposures and risks. The work has also considered detailed assessments related to other criteria pollutants that include ozone, nitrogen oxides, sulphur dioxide, particulate matter and other combustion products (such as polycyclic aromatic hydrocarbons and volatile organic compounds). Projects have involved detailed review of current literature in relation to the health effects and the identification and use of appropriate dose-response relationships relevant to the quantification of relevant health endpoints, with consultation conducted with stakeholders, including state health departments and the community. Works undertaken for the West Gate Tunnel, North East Link and Suburban Rail Loop East included the panel inquiry (presentation and attendance at the inquiry).
- 2018-2019 – Detailed assessment of particulate risks associated with power station emissions, including detailed critical peer review of public commentary papers as well as published papers and the available research underlying current understanding of health impacts from changes to particulate matter in urban and rural air environments.

- 2010 to 2023 – Detailed assessment of health impacts associated noise, as generated from major road or rail infrastructure or from aircraft noise. These assessments require an understanding of various noise guidelines, as well as current literature on the health effects of noise on the community. Assessments have included qualitative, semi-quantitative as well as quantitative assessments of risk and population incidence utilising published exposure-response relationships.
- 2016 to 2018 – Detailed assessment of roadway and tunnel design features to ensure public health is protected. This has included assessment of exposures to nitrogen dioxide and the build-up of carbon dioxide (in-cabin) in long tunnels, design of long tunnels to ensure public safety from fatigue and monotony and design of roadways to ensure flicker effects do not adversely affect road users.
- 2015 to 2023 – conduct of detailed human health and ecological risk assessments for a range of sites (in particular airport and defence sites) where PFAS issues are of potential concern both on the site and in relation to offsite migration, discharge and exposure. Work has involved detailed evaluations and the development of site-specific guidelines and management measures within the context of a moving regulatory environment.
- 2020 to 2023 – Detailed assessment of risks to human health and the environment in relation to the proposed reuse of materials in road infrastructure (considered a wide range of materials proposed for reuse, in a variety of use scenarios).
- 2008 to 2014 - Detailed evaluation of human health and environmental issues associated with a former chlor-alkali plant. The assessment involved detailed evaluation of mercury fate and transport with use of specialised data collected and analysed by CSIRO and liaison with experts on mercury issues from the CSIRO. Assessment considered environmental issues associated with the presence of mercury in groundwater and discharge to an urban (highly modified) environment, as well as issues associated with mercury (elemental and inorganic) in soil and groundwater with respect to fate and transport, human health and environmental issues.
- 2010 to 2015 (with ongoing advice to 2023) – Conduct of a detailed Health Impact Assessment in relation to major rail infrastructure development proposal at Moorebank. The HIA involved consultation with stakeholders, in particular local councils, NSW Health and the community, with all aspects of the proposal being address in relation to health impacts, both positive and negative. The HIA was peer reviewed by the University of NSW and an international expert. Ongoing advice relates to construction and operational management of PFAS.
- 2016 to 2018 – Literature review and assessment of community health impacts associated with landfill gas emissions, and emissions from water to energy facilities.
- 2018 to 2023 – Conduct of a number of detailed human health risk assessment or health impact assessments in relation to the proposed development of waste-to-energy facilities in NSW, Victoria and Queensland. A number of the projects have been approved.
- 2011 – Quantitative assessment of risks to human health associated with the placement of remediated soil that contains residual levels of radiological contamination, beneath a proposed commercial/industrial development in South Australia.
- 2011 to 2016 – Detailed evaluation and development of chemical risk assessments for a range of products/compounds utilised during coal seam gas operations in NSW and Queensland.
- 2017 to 2018 – Panel member on the WA Government Technical Enquiry on hydraulic fracturing.
- 2011 – Development of a detailed scope of works for the assessment and remediation of an abandoned asbestos mine in NSW. The works required

collaboration between key stakeholders including NSW Health and the NSW EPA with the focus of the works on the protection of off-site community health.

- 2011 to 2023 – Assessment of risk issues associated with the presence of friable and bonded asbestos materials on a range of sites, proposed to be used for residential, school or commercial/industrial purposes. The assessments include consideration of risk management measures required, monitoring requirements and establishing site specific criteria relevant for the protection of construction workers and off-site residents (as required).
- 2010 – Detailed assessment of risks (including detailed assessment of toxicity of individual compounds and mixtures) to human health associated with the presence of nitrate, nitrite and perchlorate contamination in drinking water (international project).
- 2009 to 2023 (and ongoing) – Expert support for contaminated land Auditors located in New South Wales, Victoria, Queensland, South Australia and Western Australia. Expert support has included review of human health and ecological risk assessments for a range of projects and issues.
- 2000 to 2023 - Detailed evaluation of risks to human health and the environment associated with redevelopment of large a number of gasworks sites in New South Wales and Victoria. Projects have involved the evaluation of the vapour migration pathway, including the collection of relevant soil gas and vapour emissions data to quantify exposure consistent with the proposed developments. The process required liaison with relevant site auditors, Vic EPA, SA EPA, NSW EPA and NSW Department of Health as required.
- 1995 to 2023 - Detailed evaluation, modelling and risk assessment of a number of landfill and waste depots in Australia (in New South Wales, Australian Capital Territory, Queensland and Victoria). This includes proposed waste destruction technologies, proposed waste depots and landfills, operational landfills, composting operations and closed landfills with assessments considering workers, residents and recreational users of the site and surrounding areas. Assessments undertaken have considered issues associated with the presence of a wide range of chemicals, landfill gas emissions, leachate generation and leaks, stormwater management, bioaerosols and other pathogens and bacteria.
- 1995 to 2023 (ongoing process as vapour issues are relevant for many projects) - Evaluation of vapour migration (and vapour intrusion) from numerous sources including contaminated soils and groundwater (dissolved phase and free phase) for many different chemicals, and subsequent assessment of human health risks associated with the estimated vapour concentrations. In addition, Jackie has developed and managed various techniques for the direct measurement of vapour migration in residential, recreational and industrial settings as part of the risk assessment process.
- 2009 to 2023 - Detailed evaluation of public health issues associated with recreational exposures to arsenic, lead and/or PAHs in surface soil in primary/secondary schools, sporting areas and children's playgrounds. Provision of technical advice along with appropriate general advice relevant for presentation to the public and responses to questions from the general public.
- 1995 to 2021 - Evaluation of human health risks associated with potential exposure to emissions from coal mining activities, including the assessment of potential risks and health effects associated with exposure to fine particulates.
- 1998 to 2009 - Evaluation of human health risks associated with the existence of, and potential remediation of encapsulated scheduled waste materials located near residential and recreational areas. The assessment has involved ongoing monitoring, review of toxicity and exposures on an ongoing basis, review of remediation options and risks derived from the application of preferred remediation options. The encapsulation has now been remediated.

- 2007 to 2013 – Assessment of risks to human health and the environment associated with the re-use of water (including irrigation uses) from a groundwater treatment plant located in Sydney.
- 2000 to 2005 - Evaluation of human health risks associated with a number of contaminated sites located in Abu Dhabi, Spain and Azerbaijan. These risk assessments involved assessment of human health risks using USEPA guidance as well as WHO guidance.
- 2005 to 2023 - Project management of large human health risk assessment associated with the redevelopment of explosives and munitions factories and firing ranges within various areas of NSW and Victoria.
- 1995 to 1998 - Evaluation of human health risks associated with off-site accumulation of lead from historical deposition associated with a former operating lead paint site located within a residential area in Sydney. Project involved the review of lead exposure and toxicity, identification and agreement to lead action levels relevant for residential properties located close to and further away from the former source.
- 1995 - Evaluation and coordination of a multi-pathway health risk analysis for a large contaminated site in Sydney involving the use of probabilistic risk assessment methodology.
- 2000 to 2005 - Conducting a feasibility assessment for a waste destruction facility in Sydney, using a probabilistic risk assessment methodology. Conduct of a detailed health risk assessment associated with the operation of the selected technology, including presentation to the Commission of Enquiry. Subsequent review of the process and exposures in relation to placing the facility within a rural area (as opposed to an urban area) and consideration of other multi-pathway exposures.
- 1993 - Assessment of risks to human health and the environment associated with sewage sludge incinerators at North Head and Malabar Sewage Treatment Plants.
- 1992 to 2023 (and ongoing) - Determination of preliminary remediation goals for numerous contaminated sites based on risk criteria.
- 1995 to 2023 (and ongoing) - Development of air sampling procedures and techniques to collect air data relevant to the further assessment of vapour migration pathways in a range of areas. This includes the collection of ambient air, soil gas data (active and passive and sub slab) and flux emissions.

Ecological Risk Assessment

- 1998 to 2023 (ongoing) - Derivation of risk-based criteria for a range of projects that are based on the protection of the aquatic environment. Evaluations have considered the potential for physical parameters (turbidity, pH, dissolved oxygen) and contaminants (principally metals, polycyclic aromatic hydrocarbons [PAHs], PFAS, petroleum compounds and chlorinated compounds). The evaluations include the potential for contaminants to leach from soil, migrate to groundwater and potentially discharge to a receiving environment (considered both marine and freshwater [including ephemeral] systems). Some of the assessments have required review and consideration of fate and transport modelling.
- 2009 to 2023 (ongoing) – Identification and derivation of investigation levels protective the terrestrial and aquatic environments associated with former clandestine drug laboratories in Australia. Ecological Tier 1 levels (based on available ecotoxicological data primarily from overseas studies) were identified and proposed for use in remediation guidelines with additional guidance provided in relation to sites where more detailed assessments of environmental risk issues needs to be conducted.
- 2010, 2011 and 2012 – Conduct (co-presenter) of lectures at the University of Sydney for the Risk Assessment (Human Health and Ecological) module for

undergraduates, School of Geosciences. Ecological risk assessment lectures addressed basic principles and frameworks, stressors, fate and transport, bioaccumulation, uptake, derivation of ANZECC Guidelines, reviewing available ecotoxicological studies and conduct of statistical analysis using the CSIRO Burrlioz software for establishing water guidelines.

- 2010 to 2011 – Expert witness in relation to ecotoxicological impacts of initial works proposed for the Barangaroo site in NSW.
- 2010 - Assessment and derivation of water criteria for petroleum hydrocarbons relevant to the protection of the terrestrial and aquatic environments from the reuse of urban run-off for irrigation or a public park and associated runoff into a lake. Assessment required a detailed assessment of not only phytotoxicity, but levels at which grass growth would be affected to the extent by which grass cover on an important AFL playing field would be affected.
- 2009 to 2011 – Detailed review of screening level risk ecological assessment (supporting studies and outcomes) for the discharge of contaminated groundwater into a sensitive marine environment in South Australia. Review required detailed consideration of the local environment, consideration that appropriate ecological indicator species have been selected, consideration of the range of urbanisation stressors within the environmental and potential for groundwater discharges to result in adverse effects to the aquatic environment, over and above those from urbanisation.
- 2008 to 2010 - Detailed evaluation of environmental fate and transport issues associated with a former chlor-alkali plant. The assessment involved detailed evaluation of mercury fate and transport with use of specialised data collected and analysed by CSIRO and liaison with experts on mercury issues from the CSIRO. Assessment considered ecotoxicological risks associated with the presence of mercury in groundwater and discharge to an urban (highly modified) environment.
- 1992 to 2023 (and ongoing) - Determination of preliminary remediation goals for numerous contaminated sites based on risk criteria. In relation to environmental risk issues, this has included the identification of appropriate and screening level criteria that are protective of fresh and marine environments and phytotoxic effects. Where necessary more detailed evaluations of ecotoxicological effects have been considered. This has included the design of suitable surveys and sampling programs (including microtox, microalgae, fish, crustacean, amphipod (sediments), plant and earthworm), interpretation of information and data from these studies, discussion of results with relevant regulatory parties, uncertainty analysis and reporting. These studies have been conducted for the assessment of petroleum hydrocarbon, cyanide, inorganics, ammonia, chloride, phosphorous and nitrate concentrations in soil and discharges from groundwater.
- 2000 to 2008 - Detailed evaluation of risks to human health and the environment (particularly aquatic species and sediments) associated with redevelopment of large a number of gasworks sites in New South Wales and Victoria. The project in NSW involved collaboration with sediment experts to determine the nature and extent of sediment contamination, potential for adverse ecotoxicological effects and requirements for remediation. The process required liaison with relevant site auditors and the DECCW (formerly NSW EPA) as required.
- 2007 - Assessment of risks to terrestrial and aquatic (marine water) environments associated with the re-use of water from a groundwater treatment plant located in Sydney. Water is proposed to be reused for a range of proposes that include industrial water (where it may be directly discarded to the marine environment) and irrigation where the water may affect terrestrial species and runoff may enter local water ways. The assessment considered available ecotoxicological data and guidelines available from Australian and International studies (where relevant to Australian species).

Contaminant Transport

- All of the projects listed above have involved the assessment of contaminant transport in at least one media. More specific examples are listed below:
- Vapour partitioning and transport assessed for petroleum compounds, including the development of a national database of petroleum vapour data, related to over 300 petroleum impacted sites, and detailed review of the database in conjunction with technical specialists from the USEPA. The database developed has been peer-reviewed by the USEPA and has been incorporated into the USEPA technical review of data from both the US and Australia for the purpose of determining screening distances.
- Vapour partitioning and transport assessed for chlorinated compounds at numerous contaminated sites, including the assessment of vapour risk issues at the Orica Botany site from 1994 to 2022.
- Review and use of groundwater fate and transport modelling conducted in support of numerous detailed risk assessment outcomes. Reviews have been conducted for the purpose of ensuring these models adequately address the potential movement of contaminants from a source to a point of discharge, utilising appropriate inputs and site data.
- 2008 to 2014 - Detailed evaluation of mercury fate and transport in groundwater and air (mercury vapour) with use of specialised data collected and analysed by CSIRO and liaison with experts on mercury issues from the CSIRO. Assessment considered environmental issues associated with the presence of mercury in groundwater and discharge to an urban (highly modified) environment, as well as issues associated with mercury (elemental and inorganic) in soil and groundwater with respect to fate and transport, human health and environmental issues.

Air Emissions and Vapour Assessment

- Jackie Wright is experienced in all aspects of determining air quality, including monitoring, assessing and modelling soil gas, vapour emissions and emissions from stacks and other fugitive sources. Projects include analysing dust emissions from a number of quarries and coal mines, motor vehicle emissions; modelling vapour emissions from motor vehicles and sources such as creeks, ponds and waste areas; and assessing odour emissions from sewage treatment plants.
- 2020 to 2023 – Assessment of inhalation exposures to drug residues derived from contaminated materials and within properties, prior to and post remediation.
- 2012 to 2013 – Development of petroleum vapour intrusion guidance for Australia in conjunction with CRC CARE. The project has involved the development of clear, prescriptive guidance that incorporates current science on the assessment of petroleum vapour intrusion. The guidelines being developed have been presented at a series of PVI training workshops (supported by ALGA and CRC CARE) run in Sydney, Melbourne and Perth.
- 2009 to 2023 (ongoing) - Development of a petroleum vapour database to assist in the interpretation and understanding of the behaviour of petroleum vapours in the subsurface environment. The database is unfunded and independent and has been interpreted by Jackie as well as industry experts in Australia and the US. The database has been peer-reviewed by the USEPA, and incorporated into the USEPA publication on the use of field data (from the US, Canada and Australia) to support and develop vertical exclusion/separation distances (refer to the following website for the USEPA review and access to the database developed: http://www.epa.gov/oust/cat/pvi/). This data is being used to support the development of screening distances that are being incorporated into guidance being developed in Australia and the US.

- 2005 to 2023 (ongoing) - Preparation of conceptual site models and completing screening level modelling (using published models such as Johnson & Ettinger) for the assessment of vapour migration and intrusion issues on a wide range of sites (over 200) affected by petroleum and chlorinated hydrocarbons.
- 2010 to 2023 – Detailed evaluation of community exposures and risks to PM10 and PM2.5 derived from urban (combustion – associated with road and rail infrastructure) sources as well as crustal (mining) sources. A number of urban projects have also considered community exposures and risks to other criteria pollutants that include ozone, nitrogen oxides and sulphur dioxide. Projects have involved detailed review of current literature in relation to the health effects and appropriate dose-response relationships relevant to the quantification of relevant health endpoints, with consultation conducted with stakeholders, including state health departments.
- 1995 to 2023 (ongoing) - Development of methods and approaches for the sampling and assessment of vapour (e.g. soil gas, flux emissions, indoor and ambient air). Works conducted has involved the conduct of field activities for the purpose of collecting this data.
- 1995 to 2023 (ongoing) - Interpretation and assessment of vapour data for the purpose of characterising inhalation exposures in a range of scenarios. These include existing buildings and proposed developments.

Risk Communication

- 2000 to 2023 (ongoing) - Jackie Wright has experience in the preparation and presentation (communication) of risk outcomes from a number of key projects across Australia to a range of community groups. These groups include workers and unions, residents and community action groups. Successful communication with stakeholders and the community on controversial projects including infrastructure, coal seam gas and other mining projects has been required.

Air Quality Assessment

- 1990 to 1995 – Air dispersion modelling and air quality impact assessment conducted for various mining (coal mining and quarry activities) and transport (major roadways) in NSW and Victoria. Projects included the development of emissions inventories, setting up and running air dispersion models and reporting.
- 2011 to 2015 - Air dispersion modelling conducted for the assessment of exposures (and risks to human health) to crop, grain and timber fumigants. The assessment have been undertaken based on trial data, with scaling to address commercial application.
- 2010 to 2018 - Air dispersion modelling conducted for the assessment of exposures (and risks to human health) to grain fumigants, timber fumigants, hydrogen sulphide, chlorinated compounds, silica and dust (particulate) emissions from a range of facilities. Modelling has been conducted using Screening level and mode detailed Ausplume and Calpuff dispersion modelling packages.
- 2010 to 2023 - Review of air dispersion modelling undertaken for a range of projects. The reviews have been undertaken to determine if the assessments are adequate for the purpose of understanding and characterising community health impacts. In some cases, the review has been undertaken as part of a larger assessment of public health impacts. Projects have included communication of the air quality assessment and health impact assessment to community groups.

Noise Impact assessment

- 2019 to 2022 - Systematic review of health impacts of transport noise for Waka Kotahi NZ Transport Agency in New Zealand. The work has involved a detailed systematic review of the evidence in published and grey literature in relation to the health effects of transport noise (road, rail and air) and whether the evidence is sufficient to support quantification of health impacts using exposure-response functions. The review has considered recent literature and the GRADE system of review to establish the robustness of the available publications and strength of evidence. This review considered the most recent reviews completed by the WHO and enHealth in 2018.

- 2014 to 2021 - Detailed Evaluation of Community Exposure and Risk to impacts associated with transport infrastructure projects for Transport for NSW and Transurban/Western Distributor Authority/ North East Link Authority in Victoria, Australia. Health impact assessments have included a detailed assessment of impacts from noise during construction and operation. This included a detailed review of current science in relation to health impacts of construction noise, as well as road transport noise sources. In some assessments quantitative risk assessment was required to be undertaken to address impacts on community health. Projects have included: NorthConnex (road - NSW); WestConnex projects - M4 East, New M5, M4-M5 Link (road - NSW); F6 Stage 1 (road - NSW); Gateway project (road and rail – NSW); Western Harbour Tunnel and Beaches Link (road - NSW); West Gate Tunnel (road -Victoria); North East Link (road – Victoria).
- 2016 to 2017 - Brisbane Airport Corporation, Queensland, Australia. Conduct of a review of the health impacts of aircraft noise as these relate to the identification and use of exposure response relationships for assessing health impacts, particularly related to flight paths near major airports.

Expert Witness

- Long Term Containment Facility at Nowingi, case presented in VCAT. The proponent was Major Projects Victoria, approvals application WA58772.
- Lend Lease (Millers Point) Pty Ltd and Orsats Australians for Sustainable Development Inc., Land and Environment Court Proceedings, 40965 of 2010 (NSW).
- Seppanen&Seppanen v Ipswich City Council, Minister for Economic Development Queensland and Queensland Urban Utilities (2016).
- Westgate Tunnel Project, Expert Witness, Inquiry and Advisory Committee (IAC) hearings (Victoria, August-September 2017).
- Child care centre project, Provision of advice as expert witness for ACT Government Solicitor (2017).
- Caltex Petroleum Pty Ltd v Campbelltown City Council Environment, Resources and Development Court Proceedings No 258 of 2015 (2017 to 2019) (SA).
- North East Link Expert Witness, Inquiry and Advisory Committee (IAC) hearings, Expert Witness (Victoria, 2019).
- Clermont Quarries Pty Ltd v Isaac Regional Council, ECL Dalby Pty Ltd, Chief Executive, Department of State Development, Manufacturing, Infrastructure and Planning and Environment Court (Qld), Expert witness (2019 - 2020).

Teaching

- 2010 to 2012 – Conduct of lectures at the University of Sydney for the Risk Assessment (Human Health and Ecological) module for undergraduates, School of Geosciences.
- 2009, 2010, 2012, 2013 to 2022 – Conduct of lectures at the University of Technology Sydney as part of the Contaminated Site Assessment and Management (CSARM) Professional Development Short Course, Risk Based Site Assessment.

- 2020 and 2022 – Toxicological Risk Assessment lecture to UNSW School of Business.
- 2017 – ALGA Risk Assessment Training Course: New Zealand
- 2014 – ACLCA (Qld) Training Course on Vapour Intrusion and Landfill Gas Assessment (organising and teaching) – May 2014
- 2014 and 2015 – ACLCA (SA and VIC) Training Course on Vapour Intrusion (teaching) – June 2014.
- 2013 and 2015 – ALGA Training Course on Vapour Intrusion (teaching).
- 2013 and 2015 – Vapour Intrusion Short Course. Training Course conducted at CleanUp 2013 and 2015, CRC CARE (teaching).
- 2016 – Clandestine laboratories – risk assessment (teaching) ALGA and ACTRA (separate workshops)
- 2014-2018 – Short courses/branch forums for ALGA – various issues regarding PFAS assessment, vapour intrusion, bioaccessibility methods, clandestine laboratories
- 2016 and 2018 – Short course for WasteMINZ – bioaccessibility methods
- 2010-2011 – Basic and Advanced Risk Assessment Course for Queensland Branch of the Australian Contaminated Land Consultants Association

Work History

Principal/Director/ Owner	Environmental Risk Sciences Pty Ltd	2008 (current)
Adjunct Lecturer	Flinders University	2016 (current)
Principal Environmental Scientist	URS Australia, North Sydney, NSW (formerly Woodward-Clyde)	1992 to 2008
Project Engineer	Sydney Water, Sydney, NSW	1991-1992
Environmental Scientist	Nigel Holmes & Associates, Sydney NSW	1990-1992
Assistant	Dames & Moore, Crows Nest, NSW	1988-1990

Education

BE (Hons)	University of Sydney, Bachelor of Engineering (Hons)	1989
PhD	Public Health, Health and Environment, Flinders University	2016

Professional Accreditation

Fellow of the Australasian College of Toxicology and Risk Assessment (ACTRA)

Professional Development

American College of Toxicology - Virtual Advanced Comprehensive Toxicology Online training course (25 modules) (2021)

Invited member of task force - WA EPA scientific inquiry into fracking in WA (2018)

Clandestine laboratory safety and investigator training and synthesis run by the Clandestine Laboratory Investigators Association (8-hour course, 2011)

Ecological Risk Assessment Course run through AEHS and credited by University of Massachusetts Boston (2010)

Mid-America Toxicology Course (35 hours, 2010)

Dose-Response Boot Camp run by Toxicology Excellence for Risk Assessment (TERA) (5 day course, 35 hours, 2008)

Vapor Intrusion Assessment and Mitigation Short Course run by Air & Waste Management Association (4 hours, 2006)

USEPA Human Health Risk Assessment Short Course (24 hours, 1995)

Affiliations

Member (former committee member, remains co-opted committee member), Australasian College of Toxicology and Risk Assessment (since 2007).

Member, Australian Land and Groundwater Association (since 2010).

Clean Air Society of Australia and New Zealand (re-joined 2015)

Member, Environmental Health Australia (since 2011).

Member, SETAC (Asia Pacific) (since 2011).

Member, Air & Waste Management Association (since 2006).

Member, Society for Risk Analysis (since 1997).

Member, Association for Environmental Health and Sciences Foundation (since 1997).

Awards

2020: Winner of Best Case Study (principal author), Australia New Zealand Policing Advisory Agency and National Institute of Forensic Science

2017: Winner of Best Case Study (principal author), Australia New Zealand Policing Advisory Agency and National Institute of Forensic Science

2017: Winner of ALGA Outstanding Leadership by a Woman in the Contaminated Land & Groundwater Industry

2017: Finalist of ALGA Outstanding Individual in the Contaminated Land & Groundwater Industry

Publications

Peer-reviewed journal articles:

Kerry, G.L., Ross, K.E., Wright, J.L. and Walker, G.S., 2022. A Review of Methods UUsed to Detect Methamphetamine from Indoor Air and Textiles in Confined Spaces. Toxics, 10, 710.

Kuhn, E.J., Walker, G.S., Whiley, H. Wright, J. and Ross, K.E., 2021. Overview of Current Practices in the Methamphetamine Testing and Decontamination Industry: An Australian Case Study. International Journal of Environmental Research and Public Health 18, 8917.

Wright, J., B. Symons, J. Angell, K. E. Ross and S. Walker, 2021. Current practices underestimate environmental exposures to methamphetamine: inhalation exposures are important. Journal of Exposure Science & Environmental Epidemiology 31: 45-54.

Kuhn, E.J., Walker, G.S., Wright, J., Whiley, H. and Ross, K.E., 2021. Public health challenges facing Environmental Health Officers during COVID-19: methamphetamine contamination of properties. Australian and New Zealand Journal of Public Health, 45: 9-12.

Wright, J., M. Kenneally, K. Ross and S. Walker, 2020. Environmental Methamphetamine Exposures and Health Effects in 25 Case Studies. Toxics 8 (3): 61.

Wright, J., G. S. Walker and K. E. Ross, 2019. Contamination of Homes with Methamphetamine: Is Wipe Sampling Adequate to Determine Risk? International Journal of Environmental Research and Public Health 16 (19): 3568.

Kuhn, E. J., G. S. Walker, H. Whiley, J. Wright and K. E. Ross, 2019. Household Contamination with Methamphetamine: Knowledge and Uncertainties. International Journal of Environmental Research and Public Health 16(23): 4676.

Capon, A. and J. Wright, 2019. An Australian incremental guideline for particulate matter ($PM_{2.5}$) to assist in development and planning decisions. Public Health Research & Practice 29 (4).

Wright, J., Kenneally, M. E., Edwards, J.W. and Walker, S., 2017. Adverse Health Effects Associated with Living in a Former Methamphetamine Drug Laboratory — Victoria, Australia, 2015. Morbidity and Mortality Weekly Report (MMWR) January 6, Vol.65, No. 52, p1470-1473

Wright, J., Edwards, J. and Walker, S., 2016. Exposures associated with clandestine methamphetamine drug laboratories in Australia. Reviews on Environmental Health, 31(3): 329-352.

Lahvis, M.A., Hers I., Davis, R.V., Wright, J. and DeVaull G.E., 2013. Vapor Intrusion Screening at Petroleum UST Sites. Groundwater Monitoring & Remediation.

Wright J. and Howell M., 2003. "Volatile Air Emissions from Soil or Groundwater – Are They as Significant as Model Say They Are?". In Contaminated Soils, Volume 8, Edited by Edward J. Calabrese, Paul T. Kostecki and James Dragun, p375-393.

Gorman J., Mival K., Wright J. and Howell M., 2003, Developing Risk-Based Screening Guidelines for Dioxin Management at a Melbourne Sewage Treatment Plant. Water, Science and Technology, Vol 47 No 10, pp 1-7.

Wright J., and Howell M., 1995, "Health Risk Assessment - Practical Applications Related to Air Quality Issues". Clean Air, Volume 29, No. 2, May 1995.

Government and industry publications:

Environmental Health Australia, 2019. Australian Voluntary Code of Practice, Assessment, remediation and validation: Former clandestine drug laboratories and other methamphetamine contaminated properties. Principal author.

CRC CARE, 2018. Weathered Petroleum Hydrocarbons (Silica Gel Clean-up), CRC CARE Technical Report no. 40, CRC for Contamination Assessment and Remediation of the Environment, Newcastle, Australia. Principal author.

CRC CARE, 2013. Petroleum Vapour Intrusion (PVI) Guidance. CRC Care Technical Report No 23, CRC for Contamination Assessment and remediation of the Environment, Adelaide, Australia. Principal author.

NEPM 2013 Revision (released in 2013), Schedule B4 (Guideline on Site-Specific Health Risk Assessment Methodology) and Schedule B7 (Guideline on Derivation of Health-Based Investigation Levels). Primary author of toxicological evaluations and derivation of health investigation levels and contributing author to the Schedules (conducting full revision/rework of both Schedules, including responding to public comments and comments from state health agencies).

Australian Government, 2011. Guidelines for Environmental Investigations, Remediation and Validation of former Clandestine Drug Laboratory Sites [Guidelines], April 2011. Primary author of toxicological evaluations and derivation of remeidation guidelines using risk based approach and listed contributor to main document.

Davis G.B., Wright J. and Patterson B.M., 2009. Field Assessment of Vapours, CRC CARE Technical Report no. 13, CRC for Contamination Assessment and remediation of the Environment, Adelaide, Australia.

Invited lectures

Wright, J. 2020 to 2022. Toxicological risk assessment. Guest lecture to University of New South Wales School of Business.

Wright, J., 2013. Petroleum Vapour Intrusion Guidance in Australia. AEHS 23rd Annual International Conference on Soil, Water, Energy, and Air and AEHS Foundation Annual Meeting, March 18-21, 2013, Mission Valley Marriott, San Diego, California. Invited lecture

Wright, J., 2012. Evaluation of the Australia Hydrocarbon VI Data Base: Exclusion Criteria. AEHS 22nd Annual International Conference on Soil, Water, Energy, and Air and AEHS Foundation Annual Meeting, March 19-22, 2012, Mission Valley Marriott, San Diego, California. Invited lecture.

Conference Proceedings (Oral Presentations):

Wright, J. (2021) Weathered Petroleum – Assessing the toxicity of polar metabolites vs petroleum hydrocarbons. ACTRA Annual Scientific Meeting, Sydney 26-27 August 2021

Wright, J. (2021) Risk Assessment and CSMs? Presentation to ACLCA – Western Australian branch meeting

Wright, J. (2020) Clan labs and meth contaminated properties - Risks and issues. Environmental Health Australia, Professional Development Workshop

Wright, J. and Manning, T. (2020) Basements, Really, you thought THAT was a good idea !!!!. ALGA Ecoforum 2020

Wright, J. (2020) Attenuation Factors and VI. ACLCA Webinar, 29 April 2020

Wright, J. and Manning, T. (2020) Chlorinated Hydrocarbons - Myths and Realities. ACTRA webinar (industry training) 27 February 2020

Wright J. and Stratford, M. (2020) Methamphetamine Risk Management Industry Voluntary Code of Practice. ACTRA webinar (industry training) 20 February 2020

Wright, J. and Manning, T. (2018) Perplexing guidelines: What it means for measurement, RACI PFAS Symposium, November 2018

Wright, J. (2018) Contrasting current contamination issues: Inside the home – methamphetamine, ALGA Regional Conference, Townsville October 2018

Wright, J. (2018) Contrasting current contamination issues: Outside the home – PFAS, ALGA Regional Conference, Townsville October 2018

Capon, A. and Wright, J. (2018) An Australian incremental guideline for particulate matter less than or equal or 2.5 micrometres (PM2.5). ACTRA Conference, October 2018

Manning, T. and Wright, J. (2018) Contaminated Land Risk Assessment and the Building Code of Australia, Ecoforum October 2018

Jarman, R., Wright, J., Manning, T. and Pendergast, D. (2016). Using oral bioaccessibility testing to refine exposure assessment for carcinogenic PAHs in soil. EcoForum, October 2016.

Manning, T., Wright, J., Jarman, R. and Bowles, K. (2016) Per and poly fluorinated alkyl substances – where are we, ecologically speaking? SETAC AU October 2016.

Jarman, R., Manning, T., and Wright J. (2016). Setting toxicity reference values for PFAS – what can we learn from TOXCAST and TOX21. ACTRA Annual Scientific Meeting, September 2016.

Manning, T., Wright, J., Jarman, R. and Bowles, K. (2016) Per and poly fluorinated alkyl substances – the Australian Story. EmCon 2016 September 2016.

Manning, T. and Wright, J. (2016). Particulate Risk Assessments – Issues and Challenges. EcoForum, October 2016.

Manning, T. and Wright, J. (2015). Review of Ecological Investigation Levels for Total Petroleum Hydrocarbons. 6th International Contaminated Site Remediation Conference (Cleanup 2015), September 2015.

Manning, T. and Wright, J. (2015). Particulate Risk Assessments – Issues and Challenges. 22nd Clean Air and Environment Conference, September 2015.

Wright, J. and Manning, T. (2015). Bioavailability/Bioaccessibility – Practical Considerations. ALGA Workshop, Use of Bioavailability and Bioaccessibility Techniques to Refine Assessment of Human Health Risk, November 2015.

Wright, J. and Manning, T. (2015). PAHs and Bioaccessibility. ALGA Workshop, Use of Bioavailability and Bioaccessibility Techniques to Refine Assessment of Human Health Risk, November 2015.

Manning, T. and Wright, J. (2014). Contaminated Land – How do environmental guidelines get used? SETAC-AU Conference Adelaide September 2014.

Manning, T. and Wright, J. (2014). Use of Health Impact Assessment in Environmental Impact Statements. Ecoforum Conference Gold Coast October 2014.

Wright J., 2014. Particulate Risk Assessments – Issues and Challenges. ACTRA Annual Scientific Meeting, Sydney October 9-10 2014.

Wright J. and Manning T., 2014. Health Impact Assessment – Role in EIS. Keynote presentation. Ecoforum, 29-31 October 2014, Gold Coast.

Wright J. and Manning T., 2014. Addressing Risk Perceptions through Risk Assessment. Ecoforum, 29-31 October 2014, Gold Coast.

Wright J. and Manning T., 2014. Vapour Assessment for TCE. Ecoforum, 29-31 October 2014, Gold Coast.

Wright J., Howell J. and Newell P., 2014. Assessment and Remediation of Illegal Drug Laboratories. Ecoforum, 29-31 October 2014, Gold Coast.

Wright, J., 2014. Clandestine Drug Laboratories – Understanding Exposures and Public Health. The Second International Conference on Law Enforcement and Public Health, Amsterdam 5-8 October 2014.

Wright, J. 2014. ASC NEPM – Implementation. AEBN (Australian Environment Business Network) Conference on Managing Contaminated Land, September 2014.

Wright, J. 2014. Managing Vapours – The Issues to Consider for Developers and Councils. AEBN (Australian Environment Business Network) Conference on Managing Contaminated Land, September 2014.

Wright, J., 2012. Exposure and Risk Issues associated with Clandestine Drug Laboratories – development of guidelines. British Occupational Hygiene Society (BOHS), Occupational Hygiene 2012 Conference, 24-26 April 2012, Mercure Holland House Hotel, Cardiff.

Wright, J., 2012. Risks of Not remediating Clandestine Drug Laboratories. 66th Annual Western Australian Environmental Health Australia (WA) State Conference Environmental Health: Imagine Life Without Us, 28-30 March 2012.

Wright, J, 2011. Establishing exclusion criteria from empirical data for assessing petroleum hydrocarbon vapour intrusion. CleanUp 2011: Proceedings of the 4th International Contaminated Site Remediation Conference, 11-15 September, Adelaide, Australia.

Wright, J., 2010. Review of Petroleum Vapour Data from Australia. Abstract presented at Ecoforum 2010, 3rd ALGA Annual Conference 23-24 February 2010.

Wright, J., 2010. Interpretation and Use of Soil Gas and other Vapour Data. Abstract presented at Ecoforum 2010, 3rd ALGA Annual Conference 23-24 February 2010.

Weaver T., Hassell T., Wright J., Stening J. and Apte S., 2009. Speciation and Geochemical Modelling as a Tool to Refine a Risk Assessment for Mercury in Groundwater. Presented at EcoForum, Sydney 28-30 April 2009.

Wright J. and Robinson C., 2009. The Reality of Sampling and Assessing Vapour Intrusion on Petroleum Sites. Presented at Air &Waste Management Association's Vapor Intrusion 2009, January 27-29 2009, San Diego CA.

Wright J., Lee A. and Howell M., 2008. Role of Risk-Based Concentrations in Assessment and remediation of Contaminated Sites. Presented at EcoForum, Gold Coast, 27-29 February 2008.

Wright J., Howell M. and Barnes J., 2006. Risk Assessment – Important Tool for Managing Issues on Contaminated Sites or Just a Task. Presented at Enviro06, Melbourne 2006.

Hall, A, Wright J. and Calabrese N, 2006. Ray Street Landfill – Audit Acceptance Levels for CO_2 in Redeemed Soils. Presented at Enviro06, Melbourne 2006.

Wright J. and Howell M., 2004. "Evaluation of Vapour Migration Modelling in Quantifying Exposure". Presented at Enviro04, Sydney March 2004.

Lee A., Howell M., and Wright J. 2004. "TPH – Analysis, Guidelines and Risk Assessment" Presented at Enviro04, Sydney March 2004.

Pershke D., van Merwyk T., Graham-Taylor S., Wright J., Mitchell T., and Elliot P., 2004. "Health Risk Assessment: Broadening the Horizons of the Traditional Health and Safety Approach", Presented at Enviro04, Sydney March 2004.

Wright J., Buchanan V., and Howell M., "Health Risk Assessment using Probability Density Functions". Presented at the AWWA Waste and Wastewater Conference, Brisbane 1998.

Wright J. and Buchanan V., 1996, "Uptake of Organics and Inorganics into Edible Fruit and Vegetable Crops". Presented at Intersect-96 International Symposium on Environmental Chemistry and Toxicology, Royal Australian Chemical Institute and the Australian Society for Ecotoxicology, 14-16 July 1996.

Wright J. and Howell M., 1995, "Risk Based Approach to Assessment and Management of Air Quality Issues Associated with Contaminated Sites and Hazardous Waste". Presented at Waste Management Institute (New Zealand) Inc., 7th Annual Conference and Exhibition, 31 October - 3 November, 1995.

Harrington J F, Clark L T and Wright J, 1994, "The Incineration of Sludge and its Effect on Ambient Air Quality in the Evaluation of Risk Factors for Primary School Children". Presented at Australia and New Zealand Clean Air Conference, Perth 1994.

Royston D, Clark L T and Wright J, 1993, "Chlorinated Dioxins and Furans from Combustion Sources: A review". Poster presented at the Sixth Conference of Asia Pacific Confederation of Chemical Engineering, Melbourne, 1993.

Appendix D ASL Leachate Test Report

D.1 Certificate of Analysis for Loose Asphalt Mix Following Aggregate Crushing

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order : **EM2224259**
Client : ARRB GROUP LTD
Contact : JAIMI HARRISON
Address : 80a Turner Street
Port Melbourne 3207
Telephone : ----
Project : 015430C
Order number : ----
C-O-C number : ----
Sampler : CHRYSOULA PANDELIDI
Site : ----
Quote number : ME/518/22 V3
No. of samples received : 7
No. of samples analysed : 7

Page : 1 of 15
Laboratory : Environmental Division Melbourne
Contact : Customer Services EM
Address : 4 Westall Rd Springvale VIC Australia 3171
Telephone : +61-3-8549 9600
Date Samples Received : 06-Dec-2022 14:30
Date Analysis Commenced : 11-Dec-2022
Issue Date : 21-Dec-2022 10:36

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted, unless the sampling was conducted by ALS. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Franco Lentini	LCMS Coordinator	Sydney Organics, Smithfield, NSW
Jarwis Nheu	Non-Metals Team Leader	Melbourne Inorganics, Springvale, VIC
Xing Lin	Senior Organic Chemist	Melbourne Organics, Springvale, VIC

RIGHT SOLUTIONS | RIGHT PARTNER

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contract for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
~ = Indicates an estimated value.

- EP075 (SIM): Where reported, Benzo(a)pyrene Toxicity Equivalent Quotient (TEQ) per the NEPM (2013) is the sum total of the concentration of the eight carcinogenic PAHs multiplied by their Toxicity Equivalence Factor (TEF) relative to Benzo(a)pyrene. TEF values are provided in brackets as follows: Benz(a)anthracene (0.1), Chrysene (0.01), Benzo(b+j) & Benzo(k)fluoranthene (0.1), Benzo(a)pyrene (1.0), Indeno(1.2.3.cd)pyrene (0.1), Dibenz(a.h)anthracene (1.0), Benzo(g.h.i)perylene (0.01). Less than LOR results for 'TEQ Zero' are treated as zero.
- EP075: Where reported, Benzo(a)pyrene Toxicity Equivalent Quotient (TEQ) per the NEPM (2013) is the sum total of the concentration of the eight carcinogenic PAHs multiplied by their Toxicity Equivalence Factor (TEF) relative to Benzo(a)pyrene. TEF values are provided in brackets as follows: Benz(a)anthracene (0.1), Chrysene (0.01), Benzo(b+j) & Benzo(k)fluoranthene (0.1), Benzo(a)pyrene (1.0), Indeno(1.2.3.cd)pyrene (0.1), Dibenz(a.h)anthracene (1.0), Benzo(g.h.i)perylene (0.01). Less than LOR results for 'TEQ Zero' are treated as zero.
- EP080: Where reported, Total Xylenes is the sum of the reported concentrations of m&p-Xylene and o-Xylene at or above the LOR.
- EP074: Where reported, Total Trihalomethanes is the sum of the reported concentrations of all Trihalomethanes at or above the LOR.
- EP074: Where reported, Total Trimethylbenzenes is the sum of the reported concentrations of 1.2.3-Trimethylbenzene, 1.2.4-Trimethylbenzene and 1.3.5-Trimethylbenzene at or above the LOR.
- EP075(SIM): Where reported, Total Cresol is the sum of the reported concentrations of 2-Methylphenol and 3- & 4-Methylphenol at or above the LOR.
- ALS is not NATA accredited for the analysis of leachable metals or organics in asphalt.
- EP075: Where reported, 'Sum of PAH' is the sum of the USEPA 16 priority PAHs

Analytical Results

Sub-Matrix: **ASPHALT**
(Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	7888	7889	7890	7891	7892
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00
				EM2224259-001	**EM2224259-002**	**EM2224259-003**	**EM2224259-004**	**EM2224259-005**
				Result	Result	Result	Result	Result
EN60-DI: Bottle Leaching Procedure - Inorganics/Non-Volatile Organics (Glass Vessel)								
Final pH	----	0.1	pH Unit	9.5	9.3	9.1	9.0	9.0
EN60Z-DI: Deionised Water Leach (Zero Headspace Extraction)								
Final pH	----	0.1	pH Unit	9.3	9.2	9.3	9.3	9.3

Analytical Results

Sub-Matrix: **ASPHALT** (Matrix: **SOIL**)			*Sample ID*	**7909**	**7910**	----	----	----
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EM2224259-006**	**EM2224259-007**	--------	--------	--------
				Result	Result	----	----	----
EN60-DI: Bottle Leaching Procedure - Inorganics/Non-Volatile Organics (Glass Vessel)								
Final pH	----	0.1	pH Unit	9.0	9.1	----	----	----
EN60Z-DI: Deionised Water Leach (Zero Headspace Extraction)								
Final pH	----	0.1	pH Unit	9.3	9.2	----	----	----

Analytical Results

Sub-Matrix: **DI WATER LEACHATE** (Matrix: **WATER**)			*Sample ID*	**7888**	**7889**	**7890**	**7891**	**7892**
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**EM2224259-001**	**EM2224259-002**	**EM2224259-003**	**EM2224259-004**	**EM2224259-005**
				Result	Result	Result	Result	Result
EG035W: Water Leachable Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
EP075(SIM)B: Polynuclear Aromatic Hydrocarbons								
Naphthalene	91-20-3	1.0	µg/L	**1.0**	**2.0**	<1.0	<1.0	<1.0
Acenaphthylene	208-96-8	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Acenaphthene	83-32-9	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Fluorene	86-73-7	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Phenanthrene	85-01-8	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Anthracene	120-12-7	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Fluoranthene	206-44-0	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Pyrene	129-00-0	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Benz(a)anthracene	56-55-3	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Chrysene	218-01-9	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(b+j)fluoranthene	205-99-2 205-82-3	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(k)fluoranthene	207-08-9	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(a)pyrene	50-32-8	0.5	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	193-39-5	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Dibenz(a.h)anthracene	53-70-3	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(g.h.i)perylene	191-24-2	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
^ **Sum of polycyclic aromatic hydrocarbons**	----	0.5	µg/L	**1.0**	**2.0**	<0.5	<0.5	<0.5
^ **Benzo(a)pyrene TEQ (zero)**	----	0.5	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5
EP075C: Phthalate Esters								
Dimethyl phthalate	131-11-3	2	µg/L	<2	<2	<2	<2	<2
Diethyl phthalate	84-66-2	2	µg/L	<2	<2	<2	<2	<2
Di-n-butyl phthalate	84-74-2	2	µg/L	<2	<2	<2	<2	<2
Butyl benzyl phthalate	85-68-7	2	µg/L	<2	<2	<2	<2	<2
bis(2-ethylhexyl) phthalate	117-81-7	10	µg/L	<10	<10	<10	<10	<10
Di-n-octylphthalate	117-84-0	2	µg/L	<2	<2	<2	<2	<2
^ **Sum of Phthalates**	----	2	µg/L	<2	<2	<2	<2	<2
EP080/071: Total Petroleum Hydrocarbons								
C10 - C14 Fraction	----	50	µg/L	<50	<50	<50	<50	<50
C15 - C28 Fraction	----	100	µg/L	<100	<100	<100	<100	<100
C29 - C36 Fraction	----	50	µg/L	<50	<50	<50	<50	<50
^ **C10 - C36 Fraction (sum)**	----	50	µg/L	<50	<50	<50	<50	<50
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								

Analytical Results

Sub-Matrix: **DI WATER LEACHATE**
(Matrix: **WATER**)

Compound	*CAS Number*	*LOR*	*Unit*	7888	7889	7890	7891	7892
			Sample ID	7888	7889	7890	7891	7892
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00
				EM2224259-001	**EM2224259-002**	**EM2224259-003**	**EM2224259-004**	**EM2224259-005**
				Result	Result	Result	Result	Result
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Continued								
>C10 - C16 Fraction	----	100	µg/L	<100	<100	<100	<100	<100
>C16 - C34 Fraction	----	100	µg/L	<100	<100	<100	<100	<100
>C34 - C40 Fraction	----	100	µg/L	<100	<100	<100	<100	<100
^ >C10 - C40 Fraction (sum)	----	100	µg/L	<100	<100	<100	<100	<100
^ >C10 - C16 Fraction minus Naphthalene (F2)	----	100	µg/L	<100	<100	<100	<100	<100
EP247: Phenolics and Related Compounds								
Bisphenol-A	80-05-7	0.05	µg/L	<0.05	<0.05	<0.05	<0.05	<0.05
EG005(ED093)W: Water Leachable Metals by ICPAES								
Aluminium	7429-90-5	0.10	mg/L	5.04	4.32	3.48	3.67	4.50
Arsenic	7440-38-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	7440-43-9	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium	7440-47-3	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	7440-50-8	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Lead	7439-92-1	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Nickel	7440-02-0	0.01	mg/L	0.02	0.02	0.01	0.01	0.02
Zinc	7440-66-6	0.01	mg/L	0.01	0.02	0.01	<0.01	<0.01
EP075(SIM)S: Phenolic Compound Surrogates								
Phenol-d6	13127-88-3	1.0	%	39.5	29.9	31.0	31.1	39.4
2-Chlorophenol-D4	93951-73-6	1.0	%	83.1	70.4	65.9	66.3	86.6
2.4.6-Tribromophenol	118-79-6	1.0	%	109	100	96.9	102	111
EP075(SIM)T: PAH Surrogates								
2-Fluorobiphenyl	321-60-8	1.0	%	79.3	75.1	72.8	64.8	102
Anthracene-d10	1719-06-8	1.0	%	96.7	93.4	83.1	88.6	98.4
4-Terphenyl-d14	1718-51-0	1.0	%	105	97.4	84.8	85.0	103
EP075S: Acid Extractable Surrogates								
2-Fluorophenol	367-12-4	2	%	57.1	42.6	37.3	34.2	50.8
Phenol-d6	13127-88-3	2	%	32.3	28.8	26.7	24.7	31.0
2-Chlorophenol-D4	93951-73-6	2	%	86.4	79.0	71.4	66.6	85.1
2.4.6-Tribromophenol	118-79-6	2	%	95.7	88.2	84.0	90.4	95.1
EP075T: Base/Neutral Extractable Surrogates								
Nitrobenzene-D5	4165-60-0	2	%	72.0	69.6	61.0	57.5	73.5
1.2-Dichlorobenzene-D4	2199-69-1	2	%	64.5	59.3	57.2	51.5	68.2
2-Fluorobiphenyl	321-60-8	2	%	77.3	75.4	73.3	66.6	84.8

Analytical Results

Sub-Matrix: **DI WATER LEACHATE** (Matrix: **WATER**)			*Sample ID*	**7888**	**7889**	**7890**	**7891**	**7892**
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**EM2224259-001**	**EM2224259-002**	**EM2224259-003**	**EM2224259-004**	**EM2224259-005**
				Result	Result	Result	Result	Result
EP075T: Base/Neutral Extractable Surrogates - Continued								
Anthracene-d10	1719-06-8	2	%	96.9	90.5	81.4	91.4	98.0
4-Terphenyl-d14	1718-51-0	2	%	104	92.4	82.6	94.9	98.0

Analytical Results

Sub-Matrix: **DI WATER LEACHATE** (Matrix: **WATER**)			*Sample ID*	**7909**	**7910**	----	----	----
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EM2224259-006**	**EM2224259-007**	--------	--------	--------
				Result	Result	----	----	----
EG035W: Water Leachable Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	----	----	----
EP075(SIM)B: Polynuclear Aromatic Hydrocarbons								
Naphthalene	91-20-3	1.0	µg/L	<1.0	<1.0	----	----	----
Acenaphthylene	208-96-8	1.0	µg/L	<1.0	<1.0	----	----	----
Acenaphthene	83-32-9	1.0	µg/L	<1.0	<1.0	----	----	----
Fluorene	86-73-7	1.0	µg/L	<1.0	<1.0	----	----	----
Phenanthrene	85-01-8	1.0	µg/L	<1.0	<1.0	----	----	----
Anthracene	120-12-7	1.0	µg/L	<1.0	<1.0	----	----	----
Fluoranthene	206-44-0	1.0	µg/L	<1.0	<1.0	----	----	----
Pyrene	129-00-0	1.0	µg/L	<1.0	<1.0	----	----	----
Benz(a)anthracene	56-55-3	1.0	µg/L	<1.0	<1.0	----	----	----
Chrysene	218-01-9	1.0	µg/L	<1.0	<1.0	----	----	----
Benzo(b+j)fluoranthene	205-99-2 205-82-3	1.0	µg/L	<1.0	<1.0	----	----	----
Benzo(k)fluoranthene	207-08-9	1.0	µg/L	<1.0	<1.0	----	----	----
Benzo(a)pyrene	50-32-8	0.5	µg/L	<0.5	<0.5	----	----	----
Indeno(1.2.3.cd)pyrene	193-39-5	1.0	µg/L	<1.0	<1.0	----	----	----
Dibenz(a.h)anthracene	53-70-3	1.0	µg/L	<1.0	<1.0	----	----	----
Benzo(g.h.i)perylene	191-24-2	1.0	µg/L	<1.0	<1.0	----	----	----
^ **Sum of polycyclic aromatic hydrocarbons**	----	0.5	µg/L	<0.5	<0.5	----	----	----
^ **Benzo(a)pyrene TEQ (zero)**	----	0.5	µg/L	<0.5	<0.5	----	----	----
EP075C: Phthalate Esters								
Dimethyl phthalate	131-11-3	2	µg/L	<2	<2	----	----	----
Diethyl phthalate	84-66-2	2	µg/L	<2	<2	----	----	----
Di-n-butyl phthalate	84-74-2	2	µg/L	<2	<2	----	----	----
Butyl benzyl phthalate	85-68-7	2	µg/L	<2	<2	----	----	----
bis(2-ethylhexyl) phthalate	117-81-7	10	µg/L	<10	<10	----	----	----
Di-n-octylphthalate	117-84-0	2	µg/L	<2	<2	----	----	----
^ **Sum of Phthalates**	----	2	µg/L	<2	<2	----	----	----
EP080/071: Total Petroleum Hydrocarbons								
C10 - C14 Fraction	----	50	µg/L	<50	<50	----	----	----
C15 - C28 Fraction	----	100	µg/L	<100	<100	----	----	----
C29 - C36 Fraction	----	50	µg/L	<50	<50	----	----	----
^ **C10 - C36 Fraction (sum)**	----	50	µg/L	<50	<50	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								

Analytical Results

Sub-Matrix: **DI WATER LEACHATE** (Matrix: **WATER**)			Sample ID	7909	7910	----	----	----
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	----	----	----
Compound	CAS Number	LOR	Unit	EM2224259-006	EM2224259-007	--------	--------	--------
				Result	Result	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Continued								
>C10 - C16 Fraction	----	100	µg/L	<100	<100	----	----	----
>C16 - C34 Fraction	----	100	µg/L	<100	<100	----	----	----
>C34 - C40 Fraction	----	100	µg/L	<100	<100	----	----	----
^ >C10 - C40 Fraction (sum)	----	100	µg/L	<100	<100	----	----	----
^ >C10 - C16 Fraction minus Naphthalene (F2)	----	100	µg/L	<100	<100	----	----	----
EP247: Phenolics and Related Compounds								
Bisphenol-A	80-05-7	0.05	µg/L	<0.05	<0.05	----	----	----
EG005(ED093)W: Water Leachable Metals by ICPAES								
Aluminium	7429-90-5	0.10	mg/L	4.12	5.22	----	----	----
Arsenic	7440-38-2	0.01	mg/L	<0.01	<0.01	----	----	----
Cadmium	7440-43-9	0.005	mg/L	<0.005	<0.005	----	----	----
Chromium	7440-47-3	0.01	mg/L	<0.01	<0.01	----	----	----
Copper	7440-50-8	0.01	mg/L	<0.01	<0.01	----	----	----
Lead	7439-92-1	0.01	mg/L	<0.01	<0.01	----	----	----
Nickel	7440-02-0	0.01	mg/L	0.01	0.02	----	----	----
Zinc	7440-66-6	0.01	mg/L	0.02	0.01	----	----	----
EP075(SIM)S: Phenolic Compound Surrogates								
Phenol-d6	13127-88-3	1.0	%	44.3	32.2	----	----	----
2-Chlorophenol-D4	93951-73-6	1.0	%	90.8	84.0	----	----	----
2.4.6-Tribromophenol	118-79-6	1.0	%	120	114	----	----	----
EP075(SIM)T: PAH Surrogates								
2-Fluorobiphenyl	321-60-8	1.0	%	95.3	87.6	----	----	----
Anthracene-d10	1719-06-8	1.0	%	106	83.1	----	----	----
4-Terphenyl-d14	1718-51-0	1.0	%	104	96.1	----	----	----
EP075S: Acid Extractable Surrogates								
2-Fluorophenol	367-12-4	2	%	50.7	57.1	----	----	----
Phenol-d6	13127-88-3	2	%	33.0	30.5	----	----	----
2-Chlorophenol-D4	93951-73-6	2	%	88.4	86.7	----	----	----
2.4.6-Tribromophenol	118-79-6	2	%	97.0	98.5	----	----	----
EP075T: Base/Neutral Extractable Surrogates								
Nitrobenzene-D5	4165-60-0	2	%	80.1	72.7	----	----	----
1.2-Dichlorobenzene-D4	2199-69-1	2	%	67.7	63.9	----	----	----
2-Fluorobiphenyl	321-60-8	2	%	90.0	90.4	----	----	----

Analytical Results

Sub-Matrix: **DI WATER LEACHATE** (Matrix: **WATER**)			*Sample ID*	**7909**	**7910**	----	----	----
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EM2224259-006**	**EM2224259-007**	--------	--------	--------
				Result	Result	----	----	----
EP075T: Base/Neutral Extractable Surrogates - Continued								
Anthracene-d10	1719-06-8	2	%	**104**	**96.2**	----	----	----
4-Terphenyl-d14	1718-51-0	2	%	**98.3**	**97.1**	----	----	----

Analytical Results

Sub-Matrix: **DI WATER ZHE LEACHATE**
(Matrix: **WATER**)

			Sample ID	7888	7889	7890	7891	7892
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00
Compound	*CAS Number*	*LOR*	*Unit*	EM2224259-001	EM2224259-002	EM2224259-003	EM2224259-004	EM2224259-005
				Result	Result	Result	Result	Result
EP074A: Monocyclic Aromatic Hydrocarbons								
Benzene	71-43-2	1	µg/L	<1	<1	<1	<1	<1
Toluene	108-88-3	2	µg/L	<2	<2	<2	<2	<2
Ethylbenzene	100-41-4	2	µg/L	<2	<2	<2	<2	<2
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	<2	<2	<2
Styrene	100-42-5	5	µg/L	<5	<5	<5	<5	<5
ortho-Xylene	95-47-6	2	µg/L	<2	<2	<2	<2	<2
Isopropylbenzene	98-82-8	5	µg/L	<5	<5	<5	<5	<5
n-Propylbenzene	103-65-1	5	µg/L	<5	<5	<5	<5	<5
1.3.5-Trimethylbenzene	108-67-8	5	µg/L	<5	<5	<5	<5	<5
sec-Butylbenzene	135-98-8	5	µg/L	<5	<5	<5	<5	<5
1.2.4-Trimethylbenzene	95-63-6	5	µg/L	<5	<5	<5	<5	<5
tert-Butylbenzene	98-06-6	5	µg/L	<5	<5	<5	<5	<5
p-Isopropyltoluene	99-87-6	5	µg/L	<5	<5	<5	<5	<5
n-Butylbenzene	104-51-8	5	µg/L	<5	<5	<5	<5	<5
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	20	µg/L	<20	<20	<20	<20	<20
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
C6 - C10 Fraction	C6_C10	20	µg/L	<20	<20	<20	<20	<20
^ C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	20	µg/L	<20	<20	<20	<20	<20
EP080: BTEXN								
Benzene	71-43-2	1	µg/L	<1	<1	<1	<1	<1
Toluene	108-88-3	2	µg/L	<2	<2	<2	<2	<2
Ethylbenzene	100-41-4	2	µg/L	<2	<2	<2	<2	<2
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	<2	<2	<2
ortho-Xylene	95-47-6	2	µg/L	<2	<2	<2	<2	<2
^ Total Xylenes	----	2	µg/L	<2	<2	<2	<2	<2
^ Sum of BTEX	----	1	µg/L	<1	<1	<1	<1	<1
Naphthalene	91-20-3	5	µg/L	<5	<5	<5	<5	<5
EP074S: VOC Surrogates								
1.2-Dichloroethane-D4	17060-07-0	5	%	101	104	106	104	110
Toluene-D8	2037-26-5	5	%	93.5	95.3	96.2	95.0	104
4-Bromofluorobenzene	460-00-4	5	%	92.3	93.0	91.7	91.9	101
EP080S: TPH(V)/BTEX Surrogates								

Analytical Results

Sub-Matrix: **DI WATER ZHE LEACHATE** (Matrix: **WATER**)			*Sample ID*	7888	7889	7890	7891	7892
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00	05-Dec-2022 00:00
Compound	*CAS Number*	*LOR*	*Unit*	EM2224259-001	EM2224259-002	EM2224259-003	EM2224259-004	EM2224259-005
				Result	Result	Result	Result	Result
EP080S: TPH(V)/BTEX Surrogates - Continued								
1.2-Dichloroethane-D4	17060-07-0	2	%	109	114	117	114	120
Toluene-D8	2037-26-5	2	%	92.5	93.9	94.2	93.5	103
4-Bromofluorobenzene	460-00-4	2	%	99.0	101	100	97.9	109

Analytical Results

Sub-Matrix: **DI WATER ZHE LEACHATE** (Matrix: **WATER**)			*Sample ID*	7909	7910	----	----	----
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EM2224259-006**	**EM2224259-007**	--------	--------	--------
				Result	Result	----	----	----
EP074A: Monocyclic Aromatic Hydrocarbons								
Benzene	71-43-2	1	µg/L	<1	<1	----	----	----
Toluene	108-88-3	2	µg/L	<2	<2	----	----	----
Ethylbenzene	100-41-4	2	µg/L	<2	<2	----	----	----
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	----	----	----
Styrene	100-42-5	5	µg/L	<5	<5	----	----	----
ortho-Xylene	95-47-6	2	µg/L	<2	<2	----	----	----
Isopropylbenzene	98-82-8	5	µg/L	<5	<5	----	----	----
n-Propylbenzene	103-65-1	5	µg/L	<5	<5	----	----	----
1.3.5-Trimethylbenzene	108-67-8	5	µg/L	<5	<5	----	----	----
sec-Butylbenzene	135-98-8	5	µg/L	<5	<5	----	----	----
1.2.4-Trimethylbenzene	95-63-6	5	µg/L	<5	<5	----	----	----
tert-Butylbenzene	98-06-6	5	µg/L	<5	<5	----	----	----
p-Isopropyltoluene	99-87-6	5	µg/L	<5	<5	----	----	----
n-Butylbenzene	104-51-8	5	µg/L	<5	<5	----	----	----
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	20	µg/L	<20	<20	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
C6 - C10 Fraction	C6_C10	20	µg/L	<20	<20	----	----	----
^ C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	20	µg/L	<20	<20	----	----	----
EP080: BTEXN								
Benzene	71-43-2	1	µg/L	<1	<1	----	----	----
Toluene	108-88-3	2	µg/L	<2	<2	----	----	----
Ethylbenzene	100-41-4	2	µg/L	<2	<2	----	----	----
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	----	----	----
ortho-Xylene	95-47-6	2	µg/L	<2	<2	----	----	----
^ Total Xylenes	----	2	µg/L	<2	<2	----	----	----
^ Sum of BTEX	----	1	µg/L	<1	<1	----	----	----
Naphthalene	91-20-3	5	µg/L	<5	<5	----	----	----
EP074S: VOC Surrogates								
1.2-Dichloroethane-D4	17060-07-0	5	%	108	108	----	----	----
Toluene-D8	2037-26-5	5	%	96.1	95.4	----	----	----
4-Bromofluorobenzene	460-00-4	5	%	94.2	92.9	----	----	----
EP080S: TPH(V)/BTEX Surrogates								

Analytical Results

Sub-Matrix: **DI WATER ZHE LEACHATE** (Matrix: **WATER**)			Sample ID	**7909**	**7910**	----	----	----
			Sampling date / time	05-Dec-2022 00:00	05-Dec-2022 00:00	----	----	----
Compound	CAS Number	LOR	Unit	**EM2224259-006**	**EM2224259-007**	--------	--------	--------
				Result	Result	----	----	----
EP080S: TPH(V)/BTEX Surrogates - Continued								
1.2-Dichloroethane-D4	17060-07-0	2	%	**118**	**118**	----	----	----
Toluene-D8	2037-26-5	2	%	**94.4**	**93.8**	----	----	----
4-Bromofluorobenzene	460-00-4	2	%	**101**	**99.6**	----	----	----

Surrogate Control Limits

Sub-Matrix: **DI WATER LEACHATE**

Compound	CAS Number	Recovery Limits (%)	
		Low	High
EP075(SIM)S: Phenolic Compound Surrogates			
Phenol-d6	13127-88-3	10	51
2-Chlorophenol-D4	93951-73-6	30	114
2.4.6-Tribromophenol	118-79-6	26	133
EP075(SIM)T: PAH Surrogates			
2-Fluorobiphenyl	321-60-8	35	127
Anthracene-d10	1719-06-8	44	122
4-Terphenyl-d14	1718-51-0	44	124
EP075S: Acid Extractable Surrogates			
2-Fluorophenol	367-12-4	6	83
Phenol-d6	13127-88-3	10	65
2-Chlorophenol-D4	93951-73-6	22	112
2.4.6-Tribromophenol	118-79-6	22	125
EP075T: Base/Neutral Extractable Surrogates			
Nitrobenzene-D5	4165-60-0	37	115
1.2-Dichlorobenzene-D4	2199-69-1	32	99
2-Fluorobiphenyl	321-60-8	39	116
Anthracene-d10	1719-06-8	49	123
4-Terphenyl-d14	1718-51-0	47	129

Sub-Matrix: **DI WATER ZHE LEACHATE**

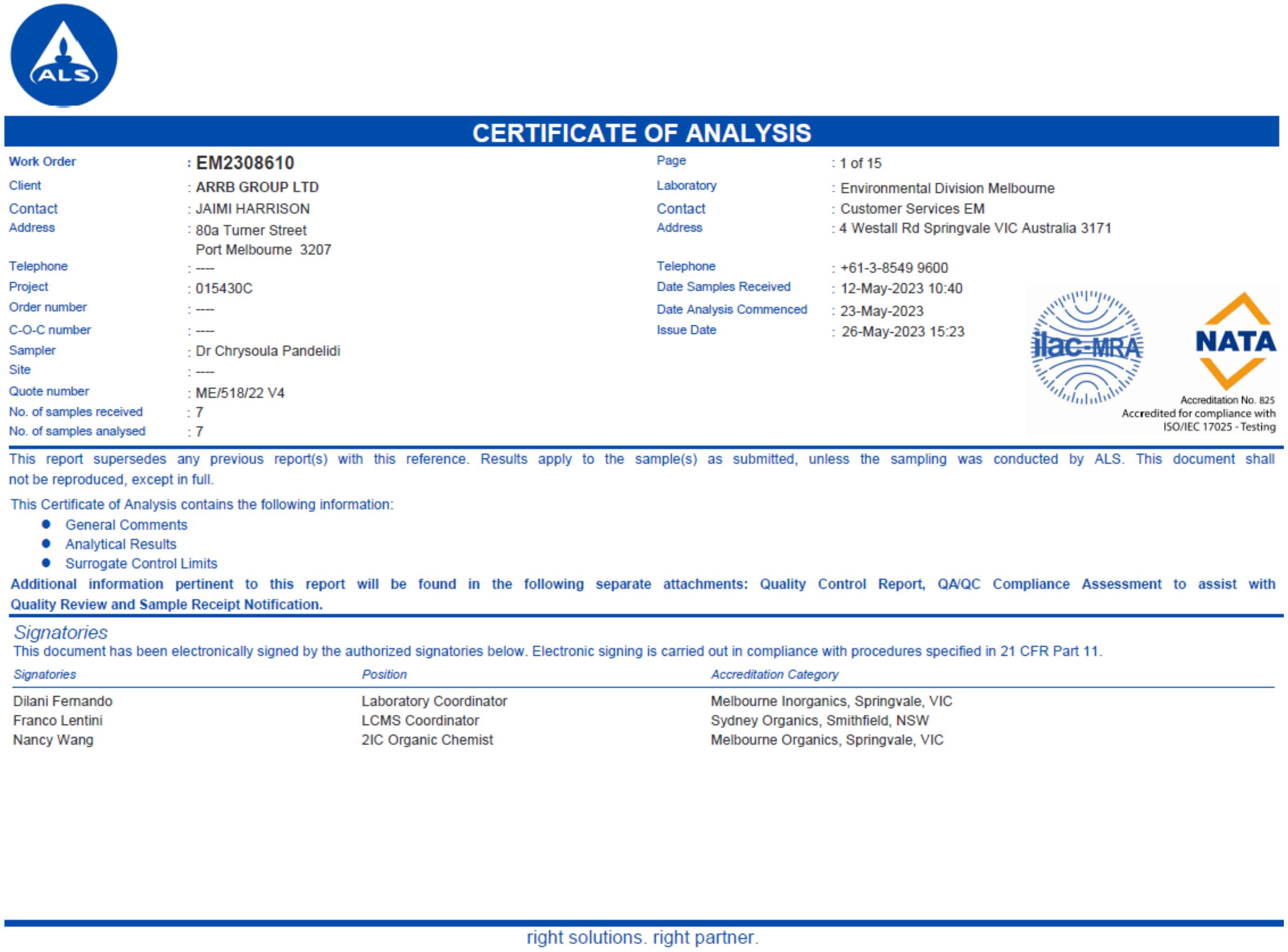
Compound	CAS Number	Recovery Limits (%)	
		Low	High
EP074S: VOC Surrogates			
1.2-Dichloroethane-D4	17060-07-0	72	132
Toluene-D8	2037-26-5	77	132
4-Bromofluorobenzene	460-00-4	67	131
EP080S: TPH(V)/BTEX Surrogates			
1.2-Dichloroethane-D4	17060-07-0	73	129
Toluene-D8	2037-26-5	70	125
4-Bromofluorobenzene	460-00-4	71	129

Inter-Laboratory Testing

Analysis conducted by ALS Sydney, NATA accreditation no. 825, site no. 10911 (Chemistry) 14913 (Biology).

(WATER) EP247: Phenolics and Related Compounds

D.2 Certificate of Analysis for Loose Asphalt Mix without Aggregate Crushing



CERTIFICATE OF ANALYSIS

Work Order : **EM2308610**
Client : ARRB GROUP LTD
Contact : JAIMI HARRISON
Address : 80a Turner Street
Port Melbourne 3207
Telephone : ----
Project : 015430C
Order number : ----
C-O-C number : ----
Sampler : Dr Chrysoula Pandelidi
Site : ----
Quote number : ME/518/22 V4
No. of samples received : 7
No. of samples analysed : 7

Page : 1 of 15
Laboratory : Environmental Division Melbourne
Contact : Customer Services EM
Address : 4 Westall Rd Springvale VIC Australia 3171
Telephone : +61-3-8549 9600
Date Samples Received : 12-May-2023 10:40
Date Analysis Commenced : 23-May-2023
Issue Date : 26-May-2023 15:23

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted, unless the sampling was conducted by ALS. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Dilani Fernando	Laboratory Coordinator	Melbourne Inorganics, Springvale, VIC
Franco Lentini	LCMS Coordinator	Sydney Organics, Smithfield, NSW
Nancy Wang	2IC Organic Chemist	Melbourne Organics, Springvale, VIC

right solutions. right partner.

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contract for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EP075 (SIM): Where reported, Benzo(a)pyrene Toxicity Equivalent Quotient (TEQ) per the NEPM (2013) is the sum total of the concentration of the eight carcinogenic PAHs multiplied by their Toxicity Equivalence Factor (TEF) relative to Benzo(a)pyrene. TEF values are provided in brackets as follows: Benz(a)anthracene (0.1), Chrysene (0.01), Benzo(b+j) & Benzo(k)fluoranthene (0.1), Benzo(a)pyrene (1.0), Indeno(1.2.3.cd)pyrene (0.1), Dibenz(a.h)anthracene (1.0), Benzo(g.h.i)perylene (0.01). Less than LOR results for 'TEQ Zero' are treated as zero.
- EP075: Where reported, Benzo(a)pyrene Toxicity Equivalent Quotient (TEQ) per the NEPM (2013) is the sum total of the concentration of the eight carcinogenic PAHs multiplied by their Toxicity Equivalence Factor (TEF) relative to Benzo(a)pyrene. TEF values are provided in brackets as follows: Benz(a)anthracene (0.1), Chrysene (0.01), Benzo(b+j) & Benzo(k)fluoranthene (0.1), Benzo(a)pyrene (1.0), Indeno(1.2.3.cd)pyrene (0.1), Dibenz(a.h)anthracene (1.0), Benzo(g.h.i)perylene (0.01). Less than LOR results for 'TEQ Zero' are treated as zero.
- EP080: Where reported, Total Xylenes is the sum of the reported concentrations of m&p-Xylene and o-Xylene at or above the LOR.
- EP074: Where reported, Total Trihalomethanes is the sum of the reported concentrations of all Trihalomethanes at or above the LOR.
- EP074: Where reported, Total Trimethylbenzenes is the sum of the reported concentrations of 1.2.3-Trimethylbenzene, 1.2.4-Trimethylbenzene and 1.3.5-Trimethylbenzene at or above the LOR.
- EP075(SIM): Where reported, Total Cresol is the sum of the reported concentrations of 2-Methylphenol and 3- & 4-Methylphenol at or above the LOR.
- EP075: Where reported, 'Sum of PAH' is the sum of the USEPA 16 priority PAHs

Analytical Results

Sub-Matrix: **ASPHALT** (Matrix: **SOIL**)			*Sample ID*	#7888	#7889	#7890	#7891	#7892
			Sampling date / time	11-May-2023 13:04	11-May-2023 13:17	11-May-2023 13:24	11-May-2023 13:31	11-May-2023 13:38
Compound	*CAS Number*	*LOR*	*Unit*	EM2308610-001	EM2308610-002	EM2308610-003	EM2308610-004	EM2308610-005
				Result	Result	Result	Result	Result
EN60-DI: Bottle Leaching Procedure - Inorganics/Non-Volatile Organics (Glass Vessel)								
Final pH	----	0.1	pH Unit	**5.8**	**9.4**	**9.7**	**9.7**	**9.7**
EN60Z-DI: Deionised Water Leach (Zero Headspace Extraction)								
Final pH	----	0.1	pH Unit	**5.1**	**9.7**	**9.7**	**9.7**	**9.7**

Analytical Results

Sub-Matrix: **ASPHALT** (Matrix: **SOIL**)			*Sample ID*	**#7909**	**#7910**	----	----	----
			Sampling date / time	11-May-2023 13:45	11-May-2023 13:51	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EM2308610-006**	**EM2308610-007**	--------	--------	--------
				Result	Result	----	----	----
EN60-DI: Bottle Leaching Procedure - Inorganics/Non-Volatile Organics (Glass Vessel)								
Final pH	----	0.1	pH Unit	**9.7**	**9.8**	----	----	----
EN60Z-DI: Deionised Water Leach (Zero Headspace Extraction)								
Final pH	----	0.1	pH Unit	**9.8**	**9.2**	----	----	----

Analytical Results

Sub-Matrix: **DI WATER LEACHATE**
(Matrix: **WATER**)

			Sample ID	#7888	#7889	#7890	#7891	#7892
			Sampling date / time	11-May-2023 13:04	11-May-2023 13:17	11-May-2023 13:24	11-May-2023 13:31	11-May-2023 13:38
Compound	CAS Number	LOR	Unit	EM2308610-001	EM2308610-002	EM2308610-003	EM2308610-004	EM2308610-005
				Result	Result	Result	Result	Result
EG035W: Water Leachable Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
EP075(SIM)B: Polynuclear Aromatic Hydrocarbons								
Naphthalene	91-20-3	1.0	µg/L	**1.1**	**2.0**	<1.0	<1.0	<1.0
Acenaphthylene	208-96-8	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Acenaphthene	83-32-9	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Fluorene	86-73-7	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Phenanthrene	85-01-8	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Anthracene	120-12-7	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Fluoranthene	206-44-0	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Pyrene	129-00-0	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Benz(a)anthracene	56-55-3	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Chrysene	218-01-9	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(b+j)fluoranthene	205-99-2 205-82-3	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(k)fluoranthene	207-08-9	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(a)pyrene	50-32-8	0.5	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	193-39-5	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Dibenz(a.h)anthracene	53-70-3	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(g.h.i)perylene	191-24-2	1.0	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0
^ Sum of polycyclic aromatic hydrocarbons	----	0.5	µg/L	**1.1**	**2.0**	<0.5	<0.5	<0.5
^ Benzo(a)pyrene TEQ (zero)	----	0.5	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5
EP075C: Phthalate Esters								
Dimethyl phthalate	131-11-3	2	µg/L	<2	<2	<2	<2	<2
Diethyl phthalate	84-66-2	2	µg/L	<2	<2	<2	<2	<2
Di-n-butyl phthalate	84-74-2	2	µg/L	<2	<2	<2	<2	<2
Butyl benzyl phthalate	85-68-7	2	µg/L	<2	<2	<2	<2	<2
bis(2-ethylhexyl) phthalate	117-81-7	10	µg/L	<10	<10	<10	<10	<10
Di-n-octylphthalate	117-84-0	2	µg/L	<2	<2	<2	<2	<2
^ Sum of Phthalates	----	2	µg/L	<2	<2	<2	<2	<2
EP080/071: Total Petroleum Hydrocarbons								
C10 - C14 Fraction	----	50	µg/L	<50	<50	<50	<50	<50
C15 - C28 Fraction	----	100	µg/L	<100	<100	<100	<100	<100
C29 - C36 Fraction	----	50	µg/L	<50	<50	<50	<50	<50
^ C10 - C36 Fraction (sum)	----	50	µg/L	<50	<50	<50	<50	<50
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			*Sample ID*	#7888	#7889	#7890	#7891	#7892
			Sampling date / time	11-May-2023 13:04	11-May-2023 13:17	11-May-2023 13:24	11-May-2023 13:31	11-May-2023 13:38
Compound	*CAS Number*	*LOR*	*Unit*	EM2308610-001	EM2308610-002	EM2308610-003	EM2308610-004	EM2308610-005
				Result	Result	Result	Result	Result
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Continued								
>C10 - C16 Fraction	----	100	µg/L	<100	<100	<100	<100	<100
>C16 - C34 Fraction	----	100	µg/L	<100	<100	<100	<100	<100
>C34 - C40 Fraction	----	100	µg/L	<100	<100	<100	<100	<100
^ >C10 - C40 Fraction (sum)	----	100	µg/L	<100	<100	<100	<100	<100
^ >C10 - C16 Fraction minus Naphthalene (F2)	----	100	µg/L	<100	<100	<100	<100	<100
EP247: Phenolics and Related Compounds								
Bisphenol-A	80-05-7	0.05	µg/L	<0.05	<0.05	<0.05	<0.05	<0.05
EG005(ED093)W: Water Leachable Metals by ICPAES								
Aluminium	7429-90-5	0.10	mg/L	3.44	3.88	2.62	2.31	3.21
Arsenic	7440-38-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	7440-43-9	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium	7440-47-3	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	7440-50-8	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Lead	7439-92-1	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Nickel	7440-02-0	0.01	mg/L	0.01	0.01	<0.01	<0.01	0.01
Zinc	7440-66-6	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
EP075(SIM)S: Phenolic Compound Surrogates								
Phenol-d6	13127-88-3	1.0	%	28.5	26.4	24.6	27.1	27.6
2-Chlorophenol-D4	93951-73-6	1.0	%	70.2	64.8	62.1	67.1	69.5
2.4.6-Tribromophenol	118-79-6	1.0	%	90.4	86.5	90.4	85.6	98.3
EP075(SIM)T: PAH Surrogates								
2-Fluorobiphenyl	321-60-8	1.0	%	74.0	69.6	66.9	71.9	73.0
Anthracene-d10	1719-06-8	1.0	%	81.2	75.2	78.3	74.4	83.2
4-Terphenyl-d14	1718-51-0	1.0	%	76.6	71.8	75.4	69.7	78.3
EP075S: Acid Extractable Surrogates								
2-Fluorophenol	367-12-4	2	%	47.1	44.9	41.8	45.3	45.4
Phenol-d6	13127-88-3	2	%	28.1	26.4	25.1	26.8	27.9
2-Chlorophenol-D4	93951-73-6	2	%	69.9	66.1	61.0	66.4	65.5
2.4.6-Tribromophenol	118-79-6	2	%	72.0	72.7	75.3	69.1	82.8
EP075T: Base/Neutral Extractable Surrogates								
Nitrobenzene-D5	4165-60-0	2	%	75.8	70.2	68.8	67.8	71.0
1.2-Dichlorobenzene-D4	2199-69-1	2	%	61.2	57.6	55.8	56.9	55.9
2-Fluorobiphenyl	321-60-8	2	%	70.5	64.4	65.0	71.3	68.6

Analytical Results

Sub-Matrix: **DI WATER LEACHATE**
(Matrix: **WATER**)

			Sample ID	#7888	#7889	#7890	#7891	#7892
			Sampling date / time	11-May-2023 13:04	11-May-2023 13:17	11-May-2023 13:24	11-May-2023 13:31	11-May-2023 13:38
Compound	CAS Number	LOR	Unit	EM2308610-001	EM2308610-002	EM2308610-003	EM2308610-004	EM2308610-005
				Result	Result	Result	Result	Result
EP075T: Base/Neutral Extractable Surrogates - Continued								
Anthracene-d10	1719-06-8	2	%	**77.0**	**73.6**	**79.8**	**72.8**	**85.0**
4-Terphenyl-d14	1718-51-0	2	%	**73.2**	**83.2**	**87.6**	**76.6**	**89.4**

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			Sample ID	#7909	#7910	----	----	----
			Sampling date / time	11-May-2023 13:45	11-May-2023 13:51	----	----	----
Compound	CAS Number	LOR	Unit	EM2308610-006	EM2308610-007	--------	--------	--------
				Result	Result	----	----	----
EG035W: Water Leachable Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	----	----	----
EP075(SIM)B: Polynuclear Aromatic Hydrocarbons								
Naphthalene	91-20-3	1.0	µg/L	<1.0	<1.0	----	----	----
Acenaphthylene	208-96-8	1.0	µg/L	<1.0	<1.0	----	----	----
Acenaphthene	83-32-9	1.0	µg/L	<1.0	<1.0	----	----	----
Fluorene	86-73-7	1.0	µg/L	<1.0	<1.0	----	----	----
Phenanthrene	85-01-8	1.0	µg/L	<1.0	<1.0	----	----	----
Anthracene	120-12-7	1.0	µg/L	<1.0	<1.0	----	----	----
Fluoranthene	206-44-0	1.0	µg/L	<1.0	<1.0	----	----	----
Pyrene	129-00-0	1.0	µg/L	<1.0	<1.0	----	----	----
Benz(a)anthracene	56-55-3	1.0	µg/L	<1.0	<1.0	----	----	----
Chrysene	218-01-9	1.0	µg/L	<1.0	<1.0	----	----	----
Benzo(b+j)fluoranthene	205-99-2 205-82-3	1.0	µg/L	<1.0	<1.0	----	----	----
Benzo(k)fluoranthene	207-08-9	1.0	µg/L	<1.0	<1.0	----	----	----
Benzo(a)pyrene	50-32-8	0.5	µg/L	<0.5	<0.5	----	----	----
Indeno(1.2.3.cd)pyrene	193-39-5	1.0	µg/L	<1.0	<1.0	----	----	----
Dibenz(a.h)anthracene	53-70-3	1.0	µg/L	<1.0	<1.0	----	----	----
Benzo(g.h.i)perylene	191-24-2	1.0	µg/L	<1.0	<1.0	----	----	----
^ Sum of polycyclic aromatic hydrocarbons	----	0.5	µg/L	<0.5	<0.5	----	----	----
^ Benzo(a)pyrene TEQ (zero)	----	0.5	µg/L	<0.5	<0.5	----	----	----
EP075C: Phthalate Esters								
Dimethyl phthalate	131-11-3	2	µg/L	<2	<2	----	----	----
Diethyl phthalate	84-66-2	2	µg/L	<2	<2	----	----	----
Di-n-butyl phthalate	84-74-2	2	µg/L	<2	<2	----	----	----
Butyl benzyl phthalate	85-68-7	2	µg/L	<2	<2	----	----	----
bis(2-ethylhexyl) phthalate	117-81-7	10	µg/L	<10	<10	----	----	----
Di-n-octylphthalate	117-84-0	2	µg/L	<2	<2	----	----	----
^ Sum of Phthalates	----	2	µg/L	<2	<2	----	----	----
EP080/071: Total Petroleum Hydrocarbons								
C10 - C14 Fraction	----	50	µg/L	<50	<50	----	----	----
C15 - C28 Fraction	----	100	µg/L	<100	<100	----	----	----
C29 - C36 Fraction	----	50	µg/L	<50	<50	----	----	----
^ C10 - C36 Fraction (sum)	----	50	µg/L	<50	<50	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								

Analytical Results

Sub-Matrix: DI WATER LEACHATE (Matrix: WATER)			Sample ID	#7909	#7910	----	----	----
			Sampling date / time	11-May-2023 13:45	11-May-2023 13:51	----	----	----
Compound	CAS Number	LOR	Unit	EM2308610-006	EM2308610-007	-------	-------	-------
				Result	Result	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Continued								
>C10 - C16 Fraction	----	100	µg/L	<100	<100	----	----	----
>C16 - C34 Fraction	----	100	µg/L	<100	<100	----	----	----
>C34 - C40 Fraction	----	100	µg/L	<100	<100	----	----	----
^ >C10 - C40 Fraction (sum)	----	100	µg/L	<100	<100	----	----	----
^ >C10 - C16 Fraction minus Naphthalene (F2)	----	100	µg/L	<100	<100	----	----	----
EP247: Phenolics and Related Compounds								
Bisphenol-A	80-05-7	0.05	µg/L	<0.05	<0.05	----	----	----
EG005(ED093)W: Water Leachable Metals by ICPAES								
Aluminium	7429-90-5	0.10	mg/L	2.60	4.13	----	----	----
Arsenic	7440-38-2	0.01	mg/L	<0.01	<0.01	----	----	----
Cadmium	7440-43-9	0.005	mg/L	<0.005	<0.005	----	----	----
Chromium	7440-47-3	0.01	mg/L	<0.01	<0.01	----	----	----
Copper	7440-50-8	0.01	mg/L	<0.01	<0.01	----	----	----
Lead	7439-92-1	0.01	mg/L	<0.01	<0.01	----	----	----
Nickel	7440-02-0	0.01	mg/L	<0.01	0.01	----	----	----
Zinc	7440-66-6	0.01	mg/L	<0.01	<0.01	----	----	----
EP075(SIM)S: Phenolic Compound Surrogates								
Phenol-d6	13127-88-3	1.0	%	24.5	33.4	----	----	----
2-Chlorophenol-D4	93951-73-6	1.0	%	60.7	83.0	----	----	----
2.4.6-Tribromophenol	118-79-6	1.0	%	79.8	105	----	----	----
EP075(SIM)T: PAH Surrogates								
2-Fluorobiphenyl	321-60-8	1.0	%	63.8	86.7	----	----	----
Anthracene-d10	1719-06-8	1.0	%	70.4	88.2	----	----	----
4-Terphenyl-d14	1718-51-0	1.0	%	66.9	82.2	----	----	----
EP075S: Acid Extractable Surrogates								
2-Fluorophenol	367-12-4	2	%	42.0	53.7	----	----	----
Phenol-d6	13127-88-3	2	%	23.6	32.0	----	----	----
2-Chlorophenol-D4	93951-73-6	2	%	57.4	77.8	----	----	----
2.4.6-Tribromophenol	118-79-6	2	%	70.8	88.2	----	----	----
EP075T: Base/Neutral Extractable Surrogates								
Nitrobenzene-D5	4165-60-0	2	%	59.9	83.7	----	----	----
1.2-Dichlorobenzene-D4	2199-69-1	2	%	51.8	70.2	----	----	----
2-Fluorobiphenyl	321-60-8	2	%	63.4	83.7	----	----	----

Analytical Results

Sub-Matrix: **DI WATER LEACHATE** (Matrix: **WATER**)			Sample ID	**#7909**	**#7910**	----	----	----
			Sampling date / time	11-May-2023 13:45	11-May-2023 13:51	----	----	----
Compound	CAS Number	LOR	Unit	**EM2308610-006**	**EM2308610-007**	--------	--------	--------
				Result	Result	----	----	----
EP075T: Base/Neutral Extractable Surrogates - Continued								
Anthracene-d10	1719-06-8	2	%	**69.0**	**87.8**	----	----	----
4-Terphenyl-d14	1718-51-0	2	%	**72.8**	**93.1**	----	----	----

Analytical Results

Sub-Matrix: **DI WATER ZHE LEACHATE**
(Matrix: **WATER**)

Compound	CAS Number	LOR	Unit	#7888	#7889	#7890	#7891	#7892
			Sample ID	#7888	#7889	#7890	#7891	#7892
			Sampling date / time	11-May-2023 13:04	11-May-2023 13:17	11-May-2023 13:24	11-May-2023 13:31	11-May-2023 13:38
Compound	*CAS Number*	*LOR*	*Unit*	EM2308610-001	EM2308610-002	EM2308610-003	EM2308610-004	EM2308610-005
				Result	Result	Result	Result	Result
EP074A: Monocyclic Aromatic Hydrocarbons								
Benzene	71-43-2	1	µg/L	<1	<1	<1	<1	<1
Toluene	108-88-3	2	µg/L	<2	<2	<2	<2	<2
Ethylbenzene	100-41-4	2	µg/L	<2	<2	<2	<2	<2
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	<2	<2	<2
Styrene	100-42-5	5	µg/L	<5	<5	<5	<5	<5
ortho-Xylene	95-47-6	2	µg/L	<2	<2	<2	<2	<2
Isopropylbenzene	98-82-8	5	µg/L	<5	<5	<5	<5	<5
n-Propylbenzene	103-65-1	5	µg/L	<5	<5	<5	<5	<5
1.3.5-Trimethylbenzene	108-67-8	5	µg/L	<5	<5	<5	<5	<5
sec-Butylbenzene	135-98-8	5	µg/L	<5	<5	<5	<5	<5
1.2.4-Trimethylbenzene	95-63-6	5	µg/L	<5	<5	<5	<5	<5
tert-Butylbenzene	98-06-6	5	µg/L	<5	<5	<5	<5	<5
p-Isopropyltoluene	99-87-6	5	µg/L	<5	<5	<5	<5	<5
n-Butylbenzene	104-51-8	5	µg/L	<5	<5	<5	<5	<5
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	20	µg/L	<20	<20	<20	<20	<20
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
C6 - C10 Fraction	C6_C10	20	µg/L	<20	<20	<20	<20	<20
^ C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	20	µg/L	<20	<20	<20	<20	<20
EP080: BTEXN								
Benzene	71-43-2	1	µg/L	<1	<1	<1	<1	<1
Toluene	108-88-3	2	µg/L	<2	<2	<2	<2	<2
Ethylbenzene	100-41-4	2	µg/L	<2	<2	<2	<2	<2
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	<2	<2	<2
ortho-Xylene	95-47-6	2	µg/L	<2	<2	<2	<2	<2
^ Total Xylenes	----	2	µg/L	<2	<2	<2	<2	<2
^ Sum of BTEX	----	1	µg/L	<1	<1	<1	<1	<1
Naphthalene	91-20-3	5	µg/L	<5	<5	<5	<5	<5
EP074S: VOC Surrogates								
1.2-Dichloroethane-D4	17060-07-0	5	%	**120**	**125**	**118**	**117**	**125**
Toluene-D8	2037-26-5	5	%	**112**	**118**	**113**	**112**	**117**
4-Bromofluorobenzene	460-00-4	5	%	**118**	**123**	**119**	**118**	**122**
EP080S: TPH(V)/BTEX Surrogates								

Analytical Results

Sub-Matrix: **DI WATER ZHE LEACHATE**
(Matrix: **WATER**)

			Sample ID	#7888	#7889	#7890	#7891	#7892
			Sampling date / time	11-May-2023 13:04	11-May-2023 13:17	11-May-2023 13:24	11-May-2023 13:31	11-May-2023 13:38
Compound	*CAS Number*	*LOR*	*Unit*	EM2308610-001	EM2308610-002	EM2308610-003	EM2308610-004	EM2308610-005
				Result	Result	Result	Result	Result
EP080S: TPH(V)/BTEX Surrogates - Continued								
1.2-Dichloroethane-D4	17060-07-0	2	%	**109**	**113**	**107**	**106**	**113**
Toluene-D8	2037-26-5	2	%	**102**	**107**	**103**	**102**	**106**
4-Bromofluorobenzene	460-00-4	2	%	**110**	**113**	**109**	**106**	**113**

Analytical Results

Sub-Matrix: **DI WATER ZHE LEACHATE** (Matrix: **WATER**)			*Sample ID*	#7909	#7910	----	----	----
			Sampling date / time	11-May-2023 13:45	11-May-2023 13:51	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	EM2308610-006	EM2308610-007	--------	--------	--------
				Result	Result	----	----	----
EP074A: Monocyclic Aromatic Hydrocarbons								
Benzene	71-43-2	1	µg/L	<1	<1	----	----	----
Toluene	108-88-3	2	µg/L	<2	<2	----	----	----
Ethylbenzene	100-41-4	2	µg/L	<2	<2	----	----	----
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	----	----	----
Styrene	100-42-5	5	µg/L	<5	<5	----	----	----
ortho-Xylene	95-47-6	2	µg/L	<2	<2	----	----	----
Isopropylbenzene	98-82-8	5	µg/L	<5	<5	----	----	----
n-Propylbenzene	103-65-1	5	µg/L	<5	<5	----	----	----
1.3.5-Trimethylbenzene	108-67-8	5	µg/L	<5	<5	----	----	----
sec-Butylbenzene	135-98-8	5	µg/L	<5	<5	----	----	----
1.2.4-Trimethylbenzene	95-63-6	5	µg/L	<5	<5	----	----	----
tert-Butylbenzene	98-06-6	5	µg/L	<5	<5	----	----	----
p-Isopropyltoluene	99-87-6	5	µg/L	<5	<5	----	----	----
n-Butylbenzene	104-51-8	5	µg/L	<5	<5	----	----	----
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	20	µg/L	<20	<20	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
C6 - C10 Fraction	C6_C10	20	µg/L	<20	<20	----	----	----
^ C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	20	µg/L	<20	<20	----	----	----
EP080: BTEXN								
Benzene	71-43-2	1	µg/L	<1	<1	----	----	----
Toluene	108-88-3	2	µg/L	<2	<2	----	----	----
Ethylbenzene	100-41-4	2	µg/L	<2	<2	----	----	----
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	<2	<2	----	----	----
ortho-Xylene	95-47-6	2	µg/L	<2	<2	----	----	----
^ Total Xylenes	----	2	µg/L	<2	<2	----	----	----
^ Sum of BTEX	----	1	µg/L	<1	<1	----	----	----
Naphthalene	91-20-3	5	µg/L	<5	<5	----	----	----
EP074S: VOC Surrogates								
1.2-Dichloroethane-D4	17060-07-0	5	%	99.9	117	----	----	----
Toluene-D8	2037-26-5	5	%	94.8	112	----	----	----
4-Bromofluorobenzene	460-00-4	5	%	98.8	117	----	----	----
EP080S: TPH(V)/BTEX Surrogates								

Analytical Results

Sub-Matrix: **DI WATER ZHE LEACHATE**
(Matrix: **WATER**)

			Sample ID	#7909	#7910	----	----	----
			Sampling date / time	11-May-2023 13:45	11-May-2023 13:51	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	EM2308610-006	EM2308610-007	-------	-------	-------
				Result	Result	----	----	----
EP080S: TPH(V)/BTEX Surrogates - Continued								
1.2-Dichloroethane-D4	17060-07-0	2	%	**90.3**	**106**	----	----	----
Toluene-D8	2037-26-5	2	%	**86.2**	**102**	----	----	----
4-Bromofluorobenzene	460-00-4	2	%	**91.7**	**109**	----	----	----

Surrogate Control Limits

Sub-Matrix: **DI WATER LEACHATE**

Compound	*CAS Number*	*Recovery Limits (%)* Low	High
EP075(SIM)S: Phenolic Compound Surrogates			
Phenol-d6	13127-88-3	10	51
2-Chlorophenol-D4	93951-73-6	30	114
2.4.6-Tribromophenol	118-79-6	26	133
EP075(SIM)T: PAH Surrogates			
2-Fluorobiphenyl	321-60-8	35	127
Anthracene-d10	1719-06-8	44	122
4-Terphenyl-d14	1718-51-0	44	124
EP075S: Acid Extractable Surrogates			
2-Fluorophenol	367-12-4	6	83
Phenol-d6	13127-88-3	10	65
2-Chlorophenol-D4	93951-73-6	22	112
2.4.6-Tribromophenol	118-79-6	22	125
EP075T: Base/Neutral Extractable Surrogates			
Nitrobenzene-D5	4165-60-0	37	115
1.2-Dichlorobenzene-D4	2199-69-1	32	99
2-Fluorobiphenyl	321-60-8	39	116
Anthracene-d10	1719-06-8	49	123
4-Terphenyl-d14	1718-51-0	47	129

Sub-Matrix: **DI WATER ZHE LEACHATE**

Compound	*CAS Number*	*Recovery Limits (%)* Low	High
EP074S: VOC Surrogates			
1.2-Dichloroethane-D4	17060-07-0	72	132
Toluene-D8	2037-26-5	77	132
4-Bromofluorobenzene	460-00-4	67	131
EP080S: TPH(V)/BTEX Surrogates			
1.2-Dichloroethane-D4	17060-07-0	73	129
Toluene-D8	2037-26-5	70	125
4-Bromofluorobenzene	460-00-4	71	129

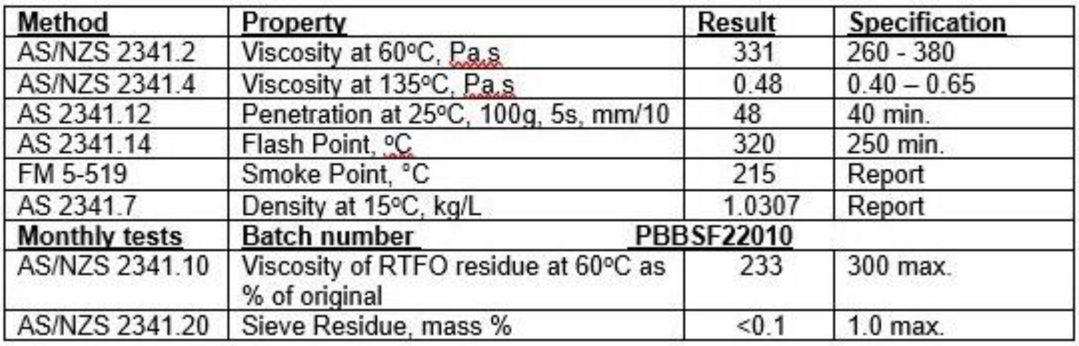
Inter-Laboratory Testing

Analysis conducted by ALS Sydney, NATA accreditation no. 825, site no. 10911 (Chemistry) 14913 (Biology).

(WATER) EP247: Phenolics and Related Compounds

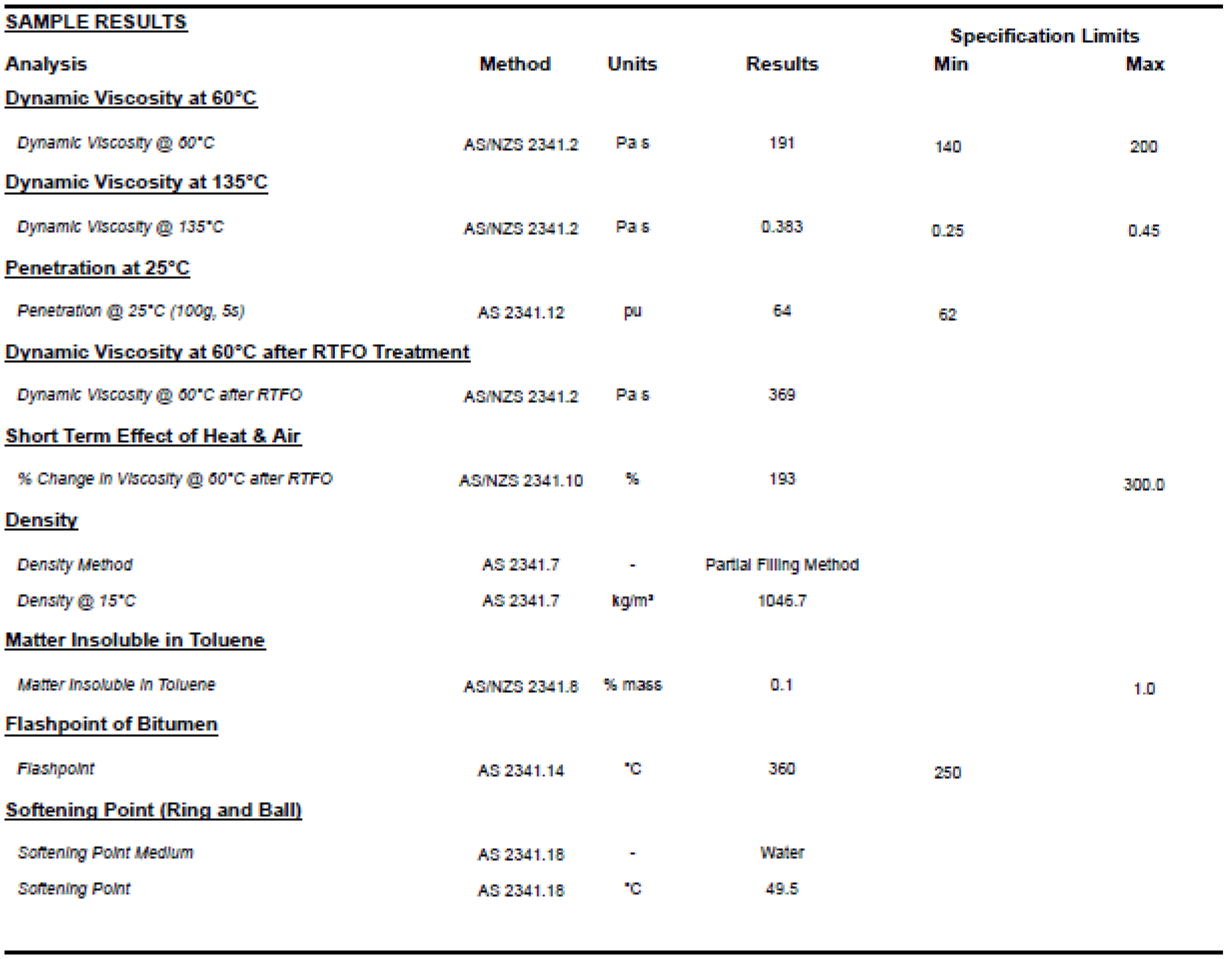
Appendix E Material Certificates

E.1 C320



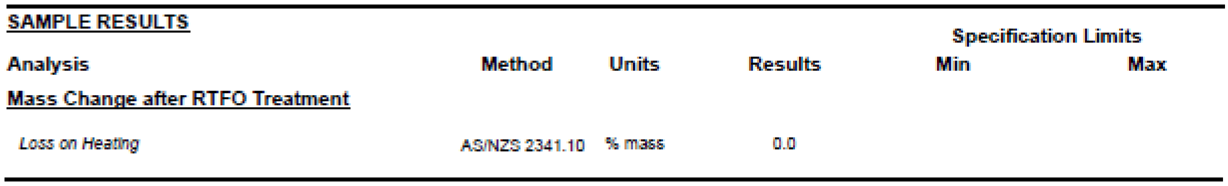
Method	Property	Result	Specification
AS/NZS 2341.2	Viscosity at 60°C, Pa.s	331	260 - 380
AS/NZS 2341.4	Viscosity at 135°C, Pa.s	0.48	0.40 – 0.65
AS 2341.12	Penetration at 25°C, 100g, 5s, mm/10	48	40 min.
AS 2341.14	Flash Point, °C	320	250 min.
FM 5-519	Smoke Point, °C	215	Report
AS 2341.7	Density at 15°C, kg/L	1.0307	Report
Monthly tests	**Batch number**	**PBBSF22010**	
AS/NZS 2341.10	Viscosity of RTFO residue at 60°C as % of original	233	300 max.
AS/NZS 2341.20	Sieve Residue, mass %	<0.1	1.0 max.

E.2 C170



SAMPLE RESULTS

Analysis	Method	Units	Results	Specification Limits Min	Max
Dynamic Viscosity at 60°C					
Dynamic Viscosity @ 60°C	AS/NZS 2341.2	Pa s	191	140	200
Dynamic Viscosity at 135°C					
Dynamic Viscosity @ 135°C	AS/NZS 2341.2	Pa s	0.383	0.25	0.45
Penetration at 25°C					
Penetration @ 25°C (100g, 5s)	AS 2341.12	pu	64	62	
Dynamic Viscosity at 60°C after RTFO Treatment					
Dynamic Viscosity @ 60°C after RTFO	AS/NZS 2341.2	Pa s	369		
Short Term Effect of Heat & Air					
% Change in Viscosity @ 60°C after RTFO	AS/NZS 2341.10	%	193		300.0
Density					
Density Method	AS 2341.7	-	Partial Filling Method		
Density @ 15°C	AS 2341.7	kg/m³	1046.7		
Matter Insoluble in Toluene					
Matter Insoluble in Toluene	AS/NZS 2341.8	% mass	0.1		1.0
Flashpoint of Bitumen					
Flashpoint	AS 2341.14	°C	360	250	
Softening Point (Ring and Ball)					
Softening Point Medium	AS 2341.18	-	Water		
Softening Point	AS 2341.18	°C	49.5		



SAMPLE RESULTS

Analysis	Method	Units	Results	Specification Limits Min	Max
Mass Change after RTFO Treatment					
Loss on Heating	AS/NZS 2341.10	% mass	0.0		

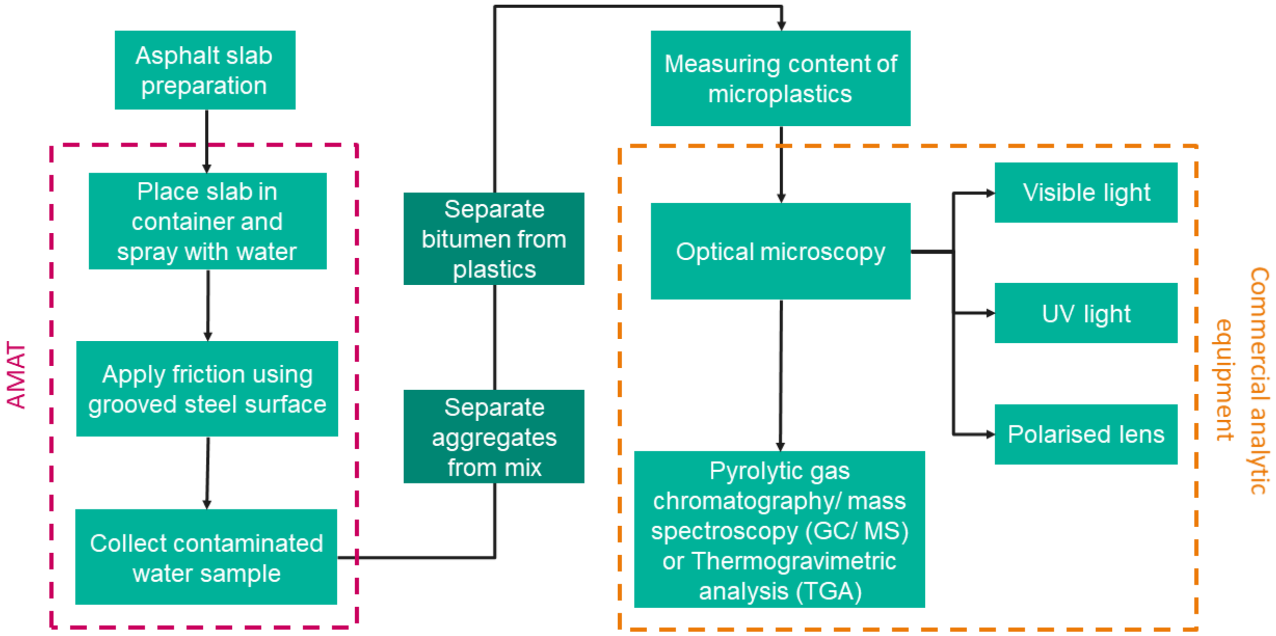
Appendix F Microplastics Quantification Methodology

F.1 Methodology Development

For the proposed methodology, 3 different pathways are presented along with their advantages and disadvantages. The aim is to accurately and reliably quantify the microplastics released in the environment, should the incorporation of waste plastics be considered for use in asphalt. It is expected that following each methodology, an accurate quantification of the impact the incorporation of different contents of plastics as well as plastics from different sources may have on the environment can be assessed. In addition, their effect on the wear of the asphalt surface may also be qualified. These methodologies are presented in Figure F.1, Figure F.2 and Figure F.3.

In Method 1, shown in Figure F.1, the requirement for continuous assessment is assumed. After the generation of the specimens using the AMAT, an optical method for the quantification of microplastics is to be used. The step requiring the use of GC/MS or TGA is included to confirm that an accurate quantification of plastics may be achieved through optical microscopy. Should such a confirmation be achieved, it is expected that the step will be eliminated and only the optical method will be used.

Figure F.1: Method 1



For this method to be successfully implemented, the separation of bitumen from the plastics is critical. This is because bitumen may mask the presence of plastics under the polarised lens resulting in the underestimation of the results. The successful separation of the bitumen from the plastics' surface requires a careful balance between the type of solvent used and time of exposure so that all bitumen is dissolved, but none of the plastics.

Method 1 advantages:

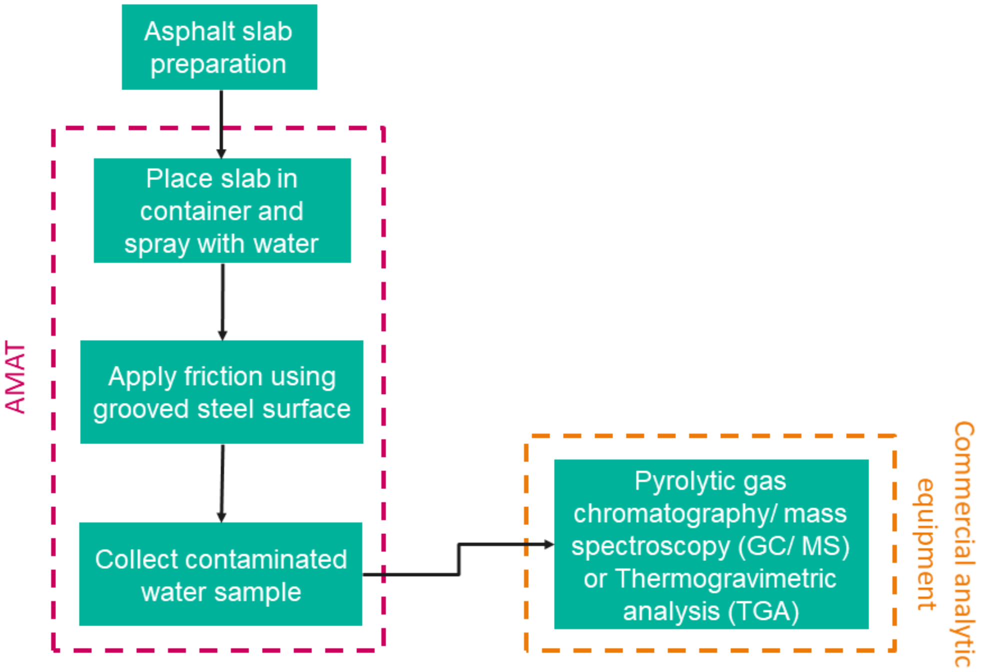
- easily accessible
- economical
- morphology of plastics may be qualified.

Method 1 disadvantages:

- time consuming
- accuracy
- bitumen separation from plastics.

Method 2, shown in Figure F.2, is the most efficient method as it eliminates the requirement of separating the components prior to their assessment. After the generation of the samples using the AMAT, 3 specimens may be collected and placed in the equipment (GC/MS or TGA) which has the ability to accurately measure the content of solids, plastics, and bitumen.

Figure F.2: Method 2



Method 2 has the potential to accurately quantify the amount of different plastics present in the specimen and identify the type of plastics. Bitumen, however, will combust around 350 °C and so the environment for testing needs to be carefully considered (inert atmosphere, such as N_2). Additionally, these processes are not readily available in laboratories and manufacturing facilities and so the tests may need to be performed by a specialist laboratory.

Method 2 advantages:

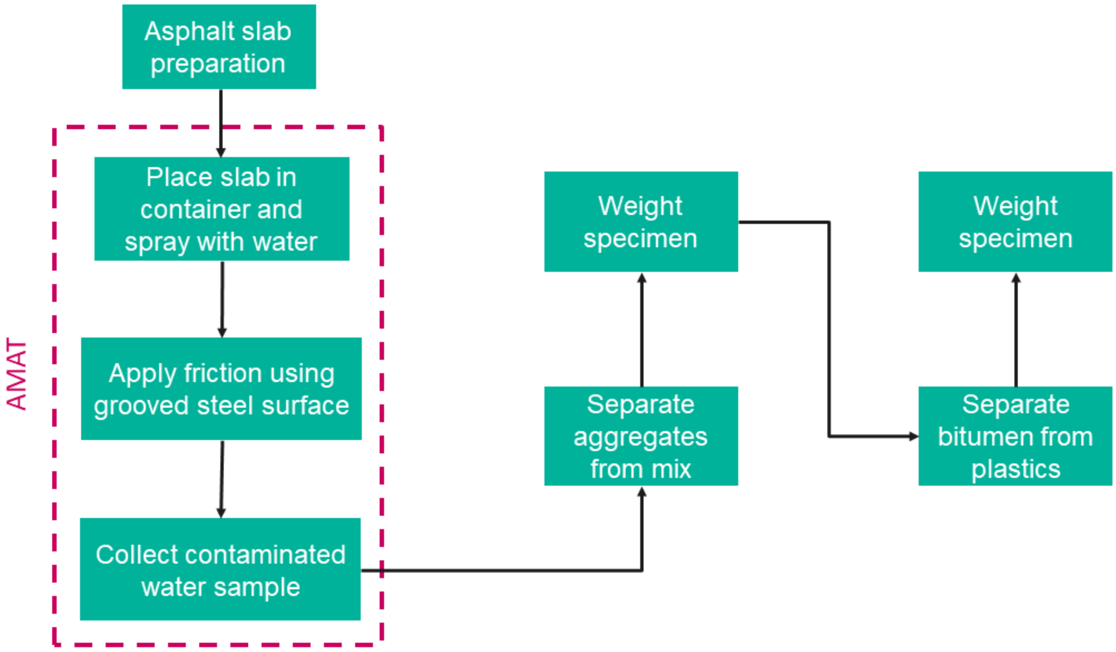
- accuracy
- time efficient
- plastics type may be identified.

Method 2 disadvantages:

- bitumen combustion
- costly.

Method 3, as shown in Figure F.3, does not require specialist equipment and therefore is proposed for cases where the continuous assessment of asphalt mixes is required at relatively low cost and when other options are not available. The use of gravimetric methods for the quantification of the components at each stage of their separation is proposed.

Figure F.3: Method 3



Method 3, however, is highly dependent on the resolution of the balances used and even though the variances in weight after the separation of aggregates from the mix may be easily identified the amount of bitumen and plastics may not be as easily quantified.

Method 3 advantages:

- does not require specialist equipment
- does not require technical expertise.

Method 3 disadvantages:

- limited accuracy
- time consuming
- bitumen separation from plastics
- balance sensitivity.

F.2 Materials

Two waste plastic materials, an engineered waste plastic and a comingled waste plastic henceforth referred to as waste plastic A and waste plastic B, respectively, were used for the fabrication of slabs. For the preliminary tests, asphalt slabs of 305 x 305 mm^2 and 50 mm in thickness were prepared using different content of controlled and comingled waste plastics in C170 bitumen. Those slabs were prepared using the wet and dry method, as specified in Table F.1.

Table F.1: Specimen naming convention, content of additives as measured during the mixing process, production method and abrading time using the AMAT

Slab ID	Additive	Additive content (wt.%)	Production method	Abrasion time (min)
SLAB A	Waste Plastic A	0.35	Wet	30
SLAB B	Waste Plastic A	0.35	Wet	60
SLAB C	Waste Plastic B	0.35	Wet	60
SLAB D	Waste Plastic B	5	Dry	60

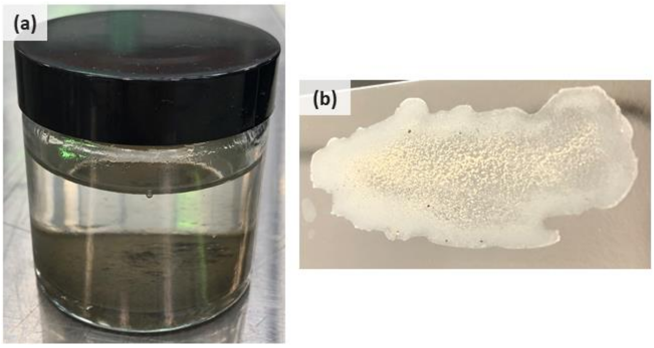
F.3 Testing Protocol

The prepared slabs were tested using the AMAT that applied friction in a rotating motion under load simulating the heaviest vehicle in Australia (approximately 20 tonnes). ISSA (2018) reported a method to measure the wearing qualities of slurry surfacing systems under wet conditions using a Hobart mixer and a rubber wheel. This method is generally referred to as the wet track abrasion test, and even though it is promising, contaminants from the rubber wheel were undesirable for the purposes of this research and so it was replaced by the steel surface.

Two specimens per sample group were fabricated. One specimen was tested in the AMAT within 24 hours of fabrication while the other specimen was aged in an air forced oven at 85 °C for 120 hours before testing, following AASHTO R30-02 (2015) to examine aging effects on the wear resistance of the fabricated slabs.

The specimens were tested coated with water to capture all released solids. A grooved steel surface was designed and manufactured to simulate the wear of asphalt on the surface. A steel surface was selected to eliminate crumb rubber contaminants that could derive from the more common rubber wheel surface used for similar abrasion tests, as described by ISSA (2018). The specimens were exposed for 30 or 60 minutes as listed in Table F.1 under 2,650 g load. Once the test was complete, water from the bath contaminated with particles detached from the slab's surface was collected, as shown in Figure F.4, and analysed.

Figure F.4: (a) Contaminated water samples as collected from the bath and (b) specimen prepared for optical microscopy



As it will be shown from the optical microscopy images of Figure F.6, more accurate visualisation of the microplastics content would be achieved if the plastics were separated from other contaminants, such as aggregates and bitumen. Another consideration is the bitumen that might have coated some plastics inhibiting their efficient imaging. It is proposed that a method to separate the aggregates from the bitumen and plastic is described first and then one to separate the bitumen from the other plastics. Mechanical methods such as sieving and floatation are to be considered for the screening of aggregates, while the use of solvents that are effective for bitumen but are not expected to affect the plastics, such as methyl chloride, might be considered for the latter. Gravimetric methods, such as the use of high precision balance are to be used throughout, so that the content of each of the contaminants can be determined.

F.4 Measuring Devices

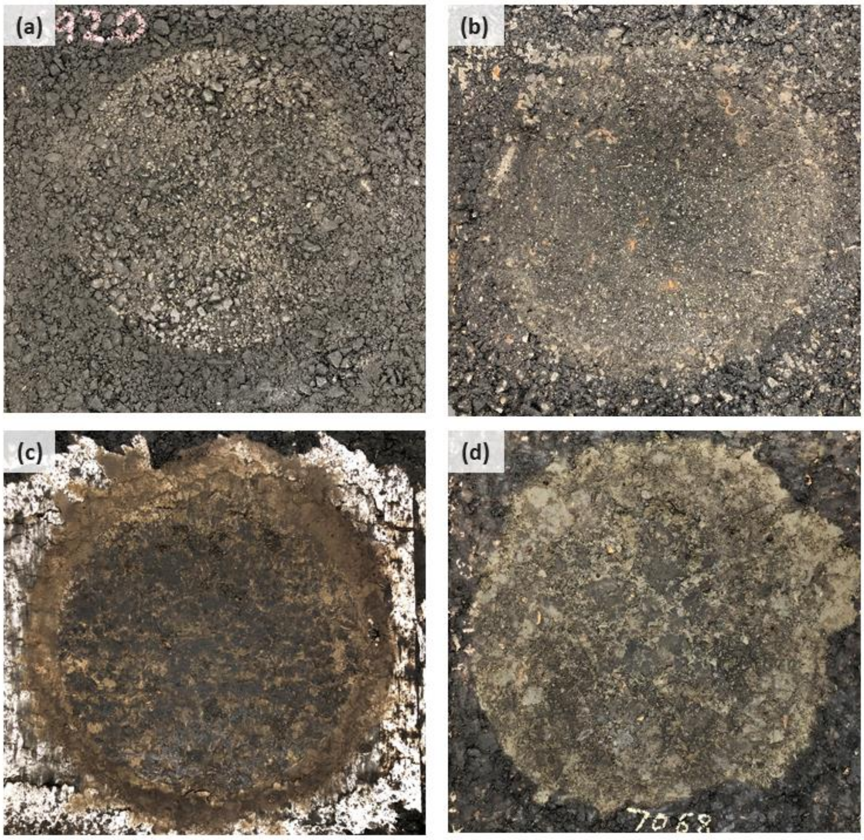
To collect satisfactory qualitative and quantitative measurements of the content of microplastics in the contaminated water, a series of analyses were performed. The aim is to develop a method to quantify the content of microplastics in the collected specimens using only optical microscopy. An Olympus SC30 optical microscope was used under visible and ultraviolet (UV) light to visually inspect the specimens.

To confirm measurements from the optical microscope, quantitative methods such as pyrolytic GC/MS and/or TGA should be considered. Other methods for analysis, such as laser direct infrared (LDIR) imaging and Fourier-transform infrared (FTIR) spectroscopy were assessed but were characterised as unsuitable as will be discussed in Appendix F.5.

F.5 Proof-of-Concept Results

In this section, proof-of-concept results for content measurements of modifiers in bitumen using the novel proposed methodology are reported. At this stage these were compiled for comingled plastic modified bitumen. In Figure F.5, images of the abraded slabs are presented. From a purely visual assessment and based on experience, it may be observed that the specimen that was prepared using the dry method (Slab D), presented notably more significant wear than the other slabs. This was probably due to the preparation method and the content of plastics included, which was in part intentional to demonstrate a worst-case scenario. Additionally, the difference in wear with an increase in abrasion time may be observed between Slabs A and B.

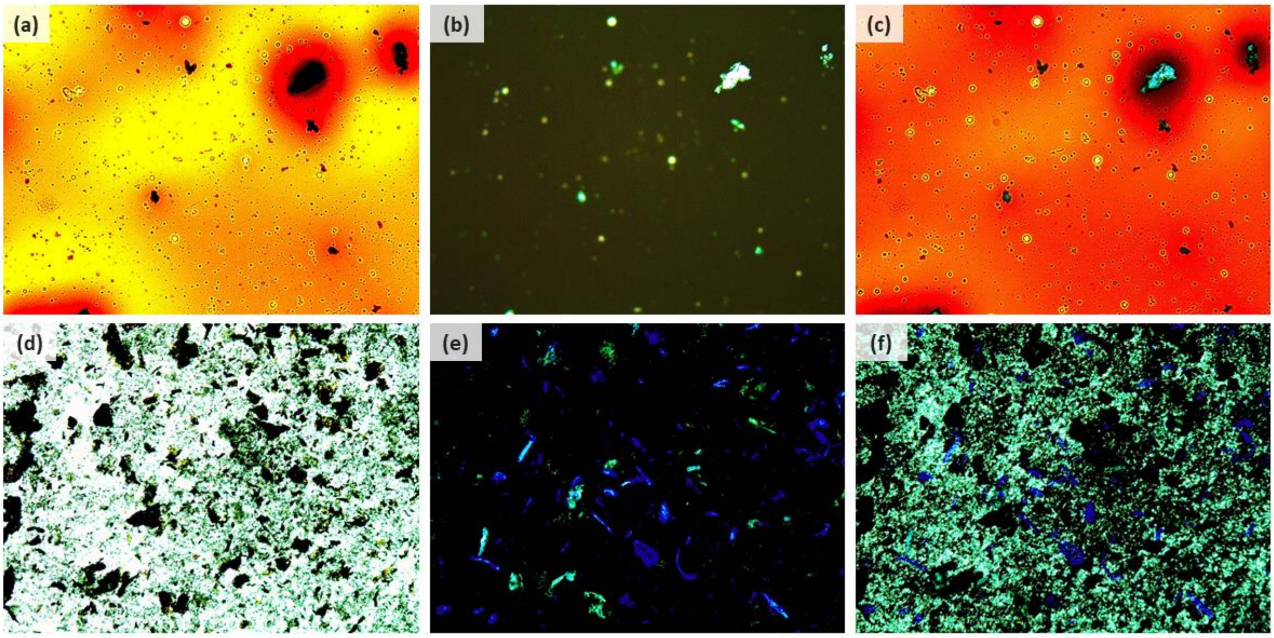
Figure F.5: AMAT abraded surface (a) Slab A, (b) Slab B, (c) Slab C, (d) Slab D



F.5.1 Optical Microscopy

Figure F.6 presents optical microscope collected images for specimens as shown in Figure F.4 (b). These specimens are expected to contain the contaminants derived from the AMAT. These would include bitumen, microplastics, and other contaminants like aggregates and sands.

Figure F.6: **Optical microscope images for (a to c) Waste Plastic A and (d to f) Waste Plastic B. (a) and (d) under visible light, (b) and (e) under UV light, and (c) and (f) under both as derived from the wet method**



In the visible light microscope images of Figure F.6 (a) and (d), the dark features are expected to be a combination of plastics, aggregates, and bitumen. The UV light was found to have the capacity to illuminate the pigment-containing plastics content within the specimen in a green hue, however, it remains unclear as to what portion of the blue illuminated particles are plastics and what portion of it is due to the other contaminants. An issue that needs to be highlighted at this stage is the contamination from the atmosphere between the collection of the sample and its assessment under the microscope. The images of Figure F.6 (c) and (f) were found to be more informative, where both visible light and UV light were used.

In this instance, a difference between Waste Plastic A and Waste Plastic B is observed. By turning on both the UV and visible light, Figure F.6 (c) highlights the plastic hue with the bitumen background. However, through the same experiment, when Waste Plastic B was considered, the discrimination among bitumen, aggregates, and plastics was more challenging. This may be attributed to the type of plastic, pigment coatings on the plastic as well as an overly concentrated sample when compared to Waste Plastic A. At this stage of the research, only the plastics that are shown in a blue colour in the Waste Plastic B sample are detectable, but the content of plastics previously illuminated in green is lost.

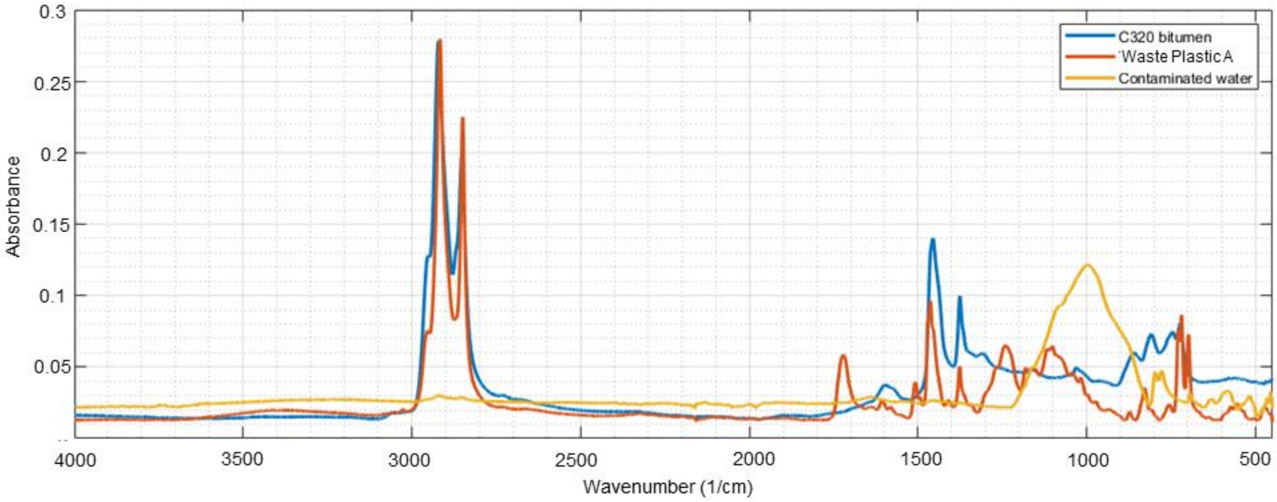
The use of a polarised lens in the microscope is expected to assist in the separation of plastics from other contaminants, such as aggregates, bitumen, and dust. Even though polymers are isotropic, their processing methods for the fabrication of consumer products induce internal stresses. Most consumer plastics are fabricated through extrusion, injection moulding, and blow moulding, all causing a directionality in the polymer chains (Committee on Polymer Science 1994). With the introduction of this anisotropicity, a birefringence is also introduced, making them detectable under polarised light.

F.5.2 Fourier-Transform Infrared Spectroscopy

FTIR was used as a method to identify the presence of microplastic contaminants in the contaminated water specimens. A Perkin Elmer Spectrum Two spectrometer was used in ATR mode to perform scans in raw waste plastic materials, unmodified bitumen, and contaminated water specimens as received from the AMAT. The scans were completed between 450 and 4,000 cm^{-1}.

Initially, the baseline materials, Waste Plastic A and the unmodified bitumen (C170), were scanned. Once the 2 materials were characterised, the contaminated specimens as collected from the AMAT were scanned in an effort to identify their composition. As it can be seen from Figure F.7, the peaks deriving from the contaminated specimen are not compatible with either of the expected polymer materials, rather they are thought to be the result of other contaminants like aggregates and sands.

Figure F.7: FTIR curves for Victorian controlled waste plastic as received, C170 unmodified bitumen, and contaminated water specimen as collected from AMAT bath



Appendix G Recommended Assessment Protocol

G.1 Fumes and Emissions Monitoring

Following the assessment of different configurations for the fumes and emissions from binders and asphalt containing recycled plastics described in Section 3, a protocol was developed encompassing the benchmarking of recycled plastics containing binders and their assessment for operator exposure in the laboratory environment. It needs to be highlighted that these methods do not discuss exposure for workers in the field or binder manufacturing facilities.

The recommended protocol is executed in 2 steps. Step 1 represents the actions and set-up proposed for benchmarking and Step 2 describes a method for the measurements of fumes and emissions that laboratory operators are exposed to during binder blending and asphalt mixing. These are presented in the flow charts below.

Enclosed test chamber fumes and emissions monitoring (Step 1) can be undertaken as a relatively quick means for benchmarking binders that contain recycled plastics against commonly used and accepted binders. Considerations for Step 1 include:

- The binders of interest need to be pre-blended, as the low shear mixer used for their agitation during these measurements cannot effectively be used for blending recycled plastics with bitumen.
- The mass poured in the flask needs to be consistent for all samples assessed.
- Careful temperature control during monitoring is required.
- Fumes emitted during initial contact of the recycled material with the bitumen cannot be quantified.

The set-up of the samplers for the enclosed test chamber fumes and emissions monitoring is presented in Figure 3.12 and allows for the measuring of VOCs, PAHs, aldehydes, TSPs, and BFs.

Step 2 should be undertaken if the measurements for the recycled plastics-containing binders exceed those of baseline materials. These measurements allow for the assessment of both the complete binder blending and asphalt mixing processes. The location of the samplers, both static and in-person, is recommended as presented in Figure 3.4. The static samplers allow for an assessment of the impact binder blending and asphalt mixing might have on operators undertaking different tasks within the vicinity of these activities, while the in-person samplers are monitoring the impact on the operators undertaking the task.

Sampling of VOCs, PAHs, aldehydes, TSPs, and BFs should be undertaken. Following Step 2, the measurements can be compared with the exposure limits set by Safe Work Australia. If the measurements are below the exposure limits, then operation in the laboratory may continue without any further modifications on the operator’s PPE.

STEP 1: Enclosed Test Chamber Fumes and Emissions Monitoring

Baseline materials and materials with recycled plastics

Static Samplers

Located at the openings of a five-neck flask

- Use of low shear mixer for agitating the binders
- Temperature = 180 °C
- RPM = 1000
- Duration: 60 min

Sampling and Analysis Methods

VOCs

Sampling: NIOSH Method 1500, NIOSH Method 1501, AS 2986.1 (0.1 L/min)
Analysis: Method WCA.2.07 (GC/ MS, solvent desorption with carbon disulphide)
LOR: 5 µg per sampling tube

PAHs

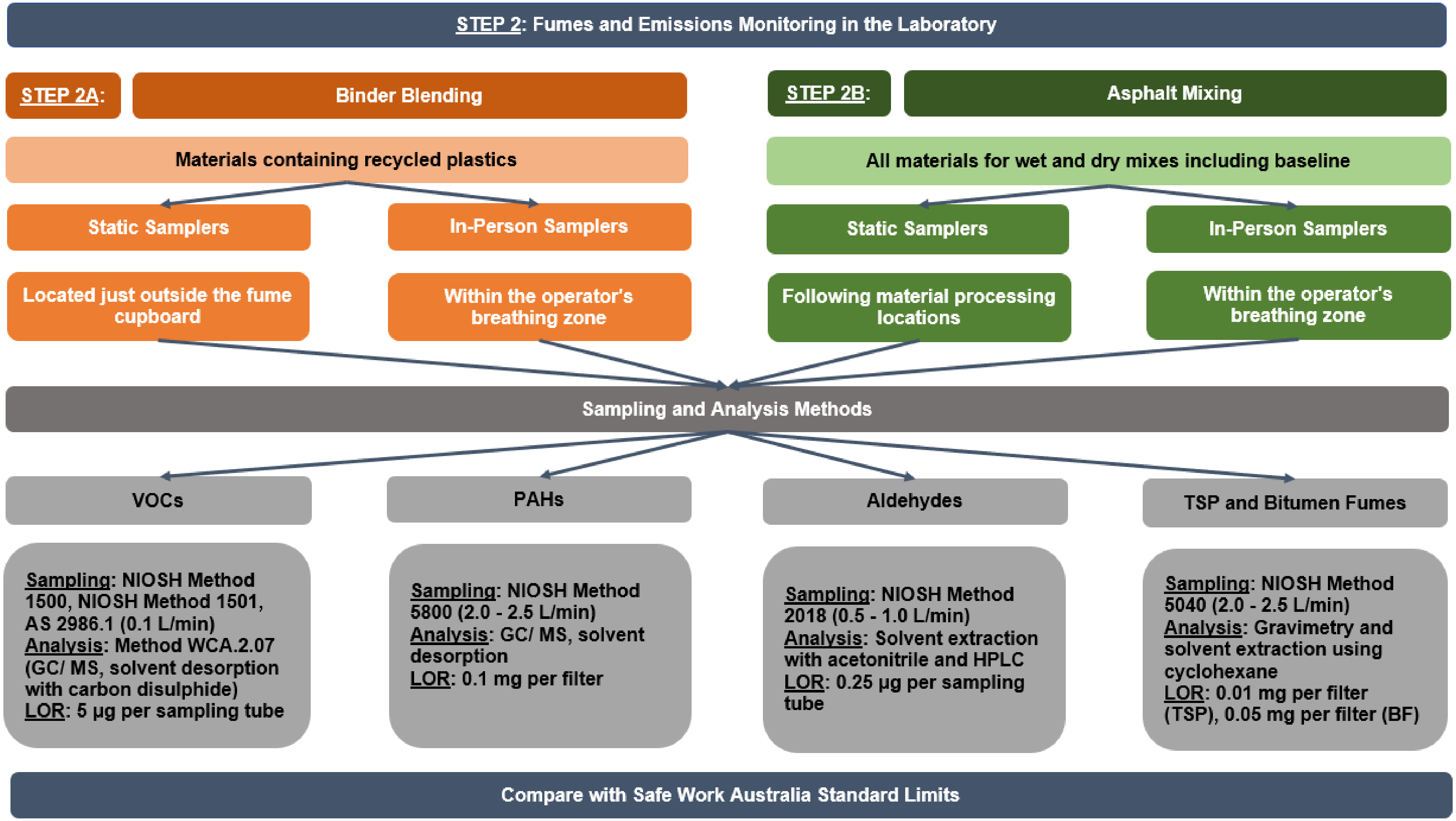
Sampling: NIOSH Method 5800 (2.0 - 2.5 L/min)
Analysis: GC/ MS, solvent desorption
LOR: 0.1 mg per filter

Aldehydes

Sampling: NIOSH Method 2018 (0.5 - 1.0 L/min)
Analysis: Solvent extraction with acetonitrile and HPLC
LOR: 0.25 µg per sampling tube

TSP and Bitumen Fumes

Sampling: NIOSH Method 5040 (2.0 - 2.5 L/min)
Analysis: Gravimetry and solvent extraction using cyclohexane
LOR: 0.01 mg per filter (TSP), 0.05 mg per filter (BF)



STEP 2: Fumes and Emissions Monitoring in the Laboratory

STEP 2A: Binder Blending

Materials containing recycled plastics

Static Samplers

Located just outside the fume cupboard

In-Person Samplers

Within the operator's breathing zone

STEP 2B: Asphalt Mixing

All materials for wet and dry mixes including baseline

Static Samplers

Following material processing locations

In-Person Samplers

Within the operator's breathing zone

Sampling and Analysis Methods

VOCs

Sampling: NIOSH Method 1500, NIOSH Method 1501, AS 2986.1 (0.1 L/min)
Analysis: Method WCA.2.07 (GC/ MS, solvent desorption with carbon disulphide)
LOR: 5 µg per sampling tube

PAHs

Sampling: NIOSH Method 5800 (2.0 - 2.5 L/min)
Analysis: GC/ MS, solvent desorption
LOR: 0.1 mg per filter

Aldehydes

Sampling: NIOSH Method 2018 (0.5 - 1.0 L/min)
Analysis: Solvent extraction with acetonitrile and HPLC
LOR: 0.25 µg per sampling tube

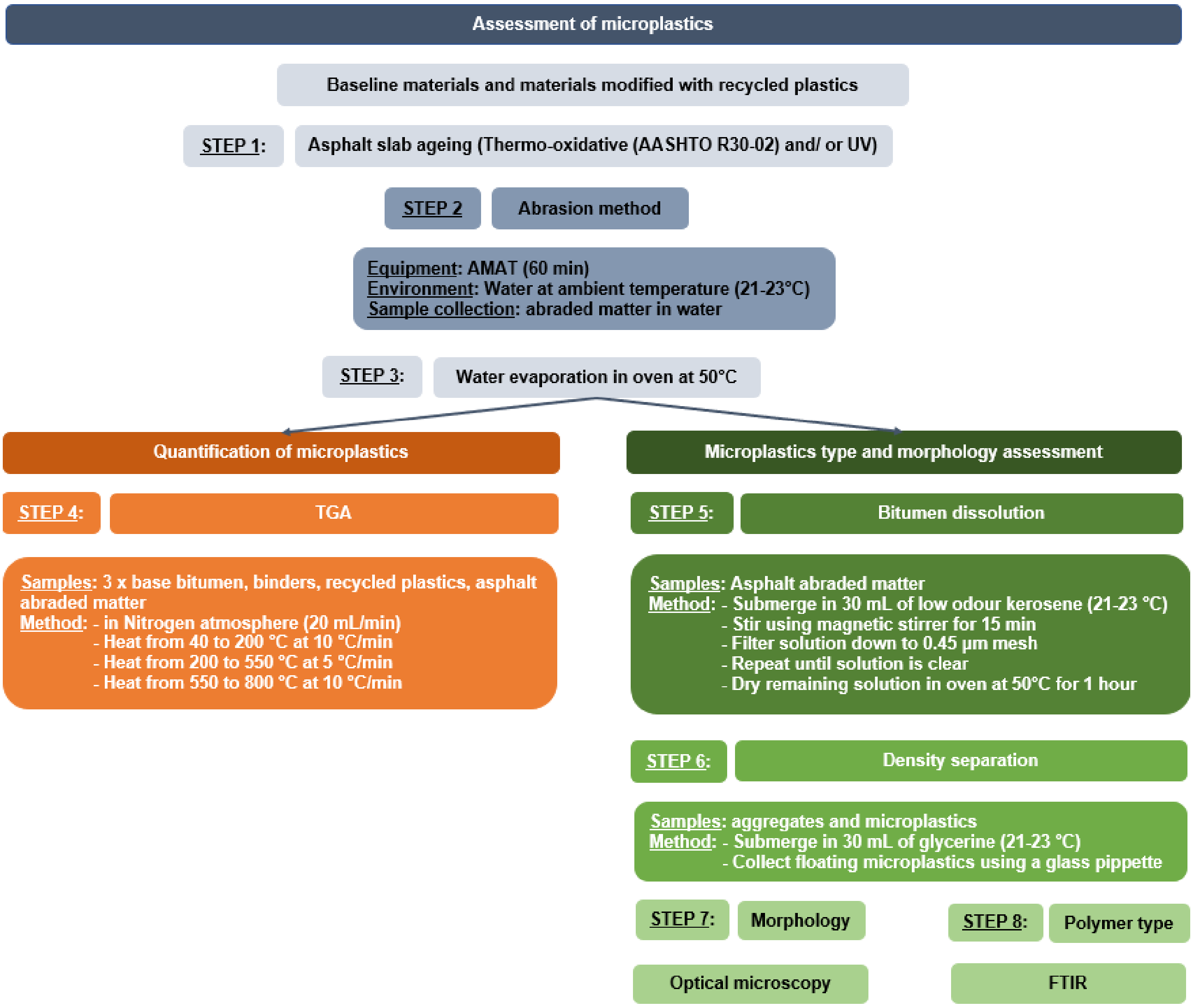
TSP and Bitumen Fumes

Sampling: NIOSH Method 5040 (2.0 - 2.5 L/min)
Analysis: Gravimetry and solvent extraction using cyclohexane
LOR: 0.01 mg per filter (TSP), 0.05 mg per filter (BF)

Compare with Safe Work Australia Standard Limits

G.2 Quantification and Qualification of Microplastics

The quantification of microplastics released following asphalt pavement abrasion was found to be achieved following Steps 1 to 4 from the flow chart below, while their qualification can be undertaken following Steps 1 to 3 and 5 to 8. This assessment should be undertaken for the materials containing recycled plastics as well as materials that are commonly used and accepted for road construction in Australia. As upper limits for microplastics released to the aquatic environment have not been set, this should be a comparative study where if an asphalt mix is found to release a greater amount of microplastics than the baseline materials, its adoption should be reconsidered.



Step 1 involves the ageing of the manufactured asphalt slabs. This is recommended as it is expected that with ageing the release of microplastics may be more rapid.

Step 2 describes the abrasion of the aged asphalt slab. In this project this was achieved using an ARRB-modified Hobart mixer (AMAT). Recommendations for the apparatus to be used include:

- a grooved steel abrasion surface
- an enclosed container to support the slab and collect the released abraded matter
- the area of the surface abraded and the rpm of the abrasion head to be controlled and known.

The asphalt slab does not need to be submerged in water, however, it is recommended that a film of water (of ambient temperature and neutral pH) is maintained on the surface. The water has 2 functions:

1. lubricates the surface of the slab to avoid overheating due to friction by the abrasion head

2. supresses the released dust.

Following abrasion, the surface of the asphalt slab is rinsed to collect all abraded matter within the container. The samples collected include the abraded matter in the water. In Step 3, the water is evaporated so that the abraded matter remains in collection trays and is further analysed. The abraded matter is expected to be comprised by aggregates, bitumen, and the selected additives.

Step 4 describes the method used for the quantification of microplastics. This is proposed to be achieved through TGA, a method widely available in analytical laboratories and universities across WA and Qld. The samples to be analysed are the collected abraded matter without further processing following drying. A total of 30 mg of material is required to analyse 3 specimens from each sample group. It is also recommended that the base binder is analysed and used as a guide for its expected degradation behaviour. Provided that the aggregates are not expected to degrade within the examined range, all mass loss following water evaporation may be attributed to the mass of the binder present.

Although research in the field is still in progress, the type and morphology of the microplastics may also need to be assessed. This may be achieved following Steps 5 to 8. Step 5 exposes the microplastics where they are coated by bitumen while Step 6 separates them from the aggregates present. Further, their morphology can be visually assessed through optical methods, such as optical microscopy, and the polymer type can be assessed through FTIR, among other spectroscopic methods.