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Technical Report: Design and Construction Guideline for the use of Crushed Recycled Concrete in Local Government Roads in WA

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About LG TRRIP

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LG TRRIP has a strategic commitment to the delivery of collaborative research and development that positively contributes to the design, construction and maintenance of safe, sustainable transport infrastructure in Western Australia.

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Summary

Construction and Demolition (C&D) material makes up approximately half of total waste generated in Western Australia and therefore represents considerable opportunity for recovery. The Roads to Reuse (RtR) program supports the supply of recycled C&D products to market that meet a product specification designed to protect human health and the environment. To enable successful use of CRC products in infrastructure projects, it is valuable to have an understanding of the unique qualities of these materials and how engineering properties can vary depending on the material's source.

CRC, in most cases, can be used as a direct replacement for granular sub-base layers with no changes to the pavement profile. It is typically only where CRC is used as a basecourse material that additional treatments need consideration.

While typically low consequence, shrinkage (block) cracking and surface defects arising from the presence of expansive materials may warrant further consideration, depending on the required level of pavement performance. Treatments to manage the risks associated with CRC may be required in some cases, and guidance is provided to assist practitioners in deciding when treatments may be required and selecting an appropriate treatment.

The *Design and Construction Guideline for the use of Crushed Recycled Concrete in Local Government Roads in WA* documents support practitioners proposing to use CRC by providing advice on material properties, case studies of existing CRC pavements, considerations when planning the use of CRC, CRC pavement designs, options to mitigate the unique risks associated with CRC use, construction advice and expected CRC pavement maintenance requirements.

While this report focuses on the engineering properties of CRC, it also provides some high-level information on potential environmental concerns.

This technical report provides background and supporting information for the accompanying guideline.

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Acronyms and Key Terms

Definition of the acronyms and key terms presented in this report are provided in Table 1.1 and Table 1.2 respectively.

Table 1.1: Acronyms

Acronym	Definition
ARRB	Australian Road Research Board
CivilSE	Civil Sciences & Engineering
C&D	Construction & Demolition
C170	Class 170 (bitumen)
CBR	California Bearing Ratio
CRB	Crushed Rock Base
CRC	Crushed Recycled Concrete
DGA	Dense Graded Asphalt
DIT	Department for Infrastructure and Transport
DWER	Department of Water and Environmental Regulation
ESA(s)	Equivalent Standard Axle(s)
FDA	Full Depth Asphalt
FWD	Falling Weight Deflectometer
GRS	Geotextile Reinforced Seal
HVAG	Heavy Vehicle Axle Group
IPWEA	Institute of Public Works Engineering Australia
LA	Los Angeles
L5D	Level 5 Design
LG(s)	Local Government(s)
LG TRRIP	Local Government Transport and Roads Research and Innovation Program
MDCS	Maximum Dry Compressive Strength
MDD	Maximum Dry Density
MMDD	Modified Maximum Dry Density
MOMC	Modified Optimum Moisture Content
MRWA	Main Roads Western Australia
N/A	Not Applicable
NATA	National Association of Testing Authorities
NSW	New South Wales
NTRO	National Transport Research Organisation
OMC	Optimum Moisture Content
PDWSA(s)	Public Drinking Water Source Area(s)
pH	Potential of Hydrogen
PTA	Public Transport Authority (of Western Australia)
QA	Quality Assurance
RAP	Reclaimed Asphalt Pavement
RtR	Roads to Reuse
SA	South Australia
SAMI(s)	Strain Alleviating Membrane Interlayer(s)
SASA	Sustainable Aggregates South Australia
SLK	Straight Line Kilometre

Acronym	Definition
TfNSW	Transport for New South Wales
TMR	Transport and Main Roads (Queensland)
UCS	Unconfined Compressive Strength
WA	Western Australia
WALGA	Western Australian Local Government Association
WSP	WSP Australia Pty Ltd

Table 1.2: Key terms

Key Term	Definition
Asphalt Geogrid	A reinforcing geogrid specifically designed for use within or immediately below asphalt layers.
Block Cracking	Cracking typically associated with shrinkage of a cementitious material, generally occurs as a “block” pattern with cracks spaced several metres apart. Also known as shrinkage cracking.
Bonded	In the context presented in this report, bonded pavement layers refers to layers which have been constructed separately, but have sufficient strength at the layer interface such as they act as a combined homogenous layer.
Bound	With regard to pavements, a material which has the ability to develop tensile strength, typically through modification with cement or bitumen. Austroads (2017) defines a bound pavement material as having a 28-day UCS >2.0 MPa.
CIRCLY	A mechanistic pavement design software program.
Class 170 (C170) Bitumen	Unmodified bitumen typically used for sprayed sealing and in the manufacture of asphalt.
Comingled CRC	CRC which has been blended with other non-cementitious recycled materials (such as aggregates, crushed brick and tile, *etc.*)
Contaminant	In the context of this report, refers to items that may be present within CRC and could cause harm to human health or the environment. Typically refers to asbestos and heavy metals.
Crack Mitigation Layer	A layer placed below the wearing surface to intercept and reduce the risk of block cracking occurring in underlying bound layers reflecting through the wearing surface.
Crushed Recycled Concrete	Material sourced from construction and demolition material primarily comprising crushed concrete. For the purpose of this report, CRC includes material that will be subject to rehydration of residual cement in the product, with behaviour in the long term similar to lightly bound, bound or modified materials as defined by Austroads (2017).
Crushed Rock Base	A basecourse-quality unbound granular pavement construction material sourced from high strength crushed rock.
Curvature	When referring to typically FWD or Benkelman Beam testing, the difference in movement of a pavement between the centre of the applied load (its deflection) and a point typically 200 mm offset from the applied load. Curvature provides an indication of the stiffness of the upper pavement layers.
Deflection	When referring to typically FWD or Benkelman Beam testing, the movement of a pavement (its “deflection”) directly under an applied load. Deflection provides an indication of the overall pavement and subgrade stiffness.
Fatigue Cracking	Cracking in a bound layer (typically asphalt or a cementitious layer) induced by the repeated action of traffic. Typically evidenced by crocodile cracking, but may present as tightly-spaced block-shaped (square) cracks typically confined to the wheel path when occurring in a bound pavement layer.

Key Term	Definition
Foreign Material	Material which does not form part of the CRC source material (i.e. concrete) such as solid metals, aggregates, asphalt, paper, glass, organics *etc.*
Geotextile Reinforced Seal	A sprayed seal which contains a layer of geotextile.
Impurity	In the context of this report, refers to foreign material that may affect the performance of CRC when used in a pavement. Typically refers to metallic aluminium and gypsum.
Mentimeter	An online survey tool.
Modified	A modified pavement material is typically an unbound granular material which has had a small amount of stabilising agent added (such as bitumen or cement), without causing a significant increase in tensile strength. Austroads (2017) defines a modified pavement material as having a 28-day UCS <1.0 MPa.
Pozzolan	A material which has negligible cementitious properties, but which may react with calcium hydroxide in the presence of water to create cementitious compounds.
Reflection Cracking	The occurrence of cracking in a wearing surface (usually asphalt) induced by cracking which commenced in an underlying layer. Typically relates to block cracking in an underlying cementitious layer presenting at the surface of the asphalt.
Resilient Modulus	The modulus (stiffness) of a material under small, rapidly applied loads. Different to the Young's modulus which is for slower loading rate.
S20E	A polymer modified bitumen used for sprayed sealing.
S45R	A rubber modified bitumen used for sprayed sealing.
Shrinkage Cracking	Block Cracking.
Straight Line Kilometre	A method of measuring chainage used by MRWA.
Strain Alleviating Membrane Interlayer	A sprayed seal using a modified bitumen (such as S20E or S45R) intended for use below an asphalt wearing course. Not intended to by trafficked until construction of the overlying asphalt is complete.
Unbonded	In the context presented in this report, unbonded pavement layers refers to layers which have been constructed separately, but have insufficient strength at the layer interface to act as a combined homogenous layer.
Unbound	A granular pavement material that does not develop significant tensile strength. Strength of unbound materials predominantly occurs through interparticle friction.
Unconfined Compressive Strength	The maximum axial compressive stress that a sample can withstand under zero confining stress
Workability	The ease of which a construction material can be handled, moisture conditioned, placed, compacted and trimmed. A workable material is generally easy to manage on site during construction works.

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1 Introduction

1.1 Background

This report presenting a *Design and Construction Guideline for the use of Crushed Recycled Concrete in Local Government Roads in WA* has been prepared for WALGA under LG TRRIP, which is a program undertaking innovative research targeted for Local Governments in WA.

The objective of the program is to achieve better implementation of innovative practice by improving the specialist capability of Local Government through a collaborative program of projects which deliver advanced technology, cost effective and practical solutions.

LG TRRIP is managed by WALGA and MRWA with the assistance of NTRO.

A considerable amount of suitable construction materials have historically been sent to landfill, with C&D material in particular making up approximately half of the total waste generated in WA. There is opportunity to recover this material for use in construction, with potential benefits including a reduction in reliance on virgin materials, reduced landfill requirements and lower emissions associated with waste transport. The RtR program has been developed to ensure that recycled C&D products meet a product specification designed to protect human health and the environment.

CRC is a valuable C&D material, and a construction resource that is suitable for use in construction of pavements. This report and associated guideline have been prepared to facilitate wider use of CRC in local roads for LG pavements, and to help asset owners understand how CRC pavements may perform. This will help LGs make informed decisions on the suitability of CRC for use on their road network.

1.2 Definition of CRC

CRC is sourced from C&D material that primarily comprises concrete, but may also contain sand, brick, tile, asphalt and glass. It is typically a high strength pavement construction material and has self-cementing properties, with an increase in stiffness over time as residual cement present in the material rehydrates. CRC can behave as a “lightly bound” pavement material in the longer term as this rehydration occurs (MRWA, 2022).

1.3 Advantages of using CRC

CRC has a number of advantages over traditional pavement construction materials, including:

- CRC has significant sustainability benefits compared with virgin materials and reduces our reliance on quarried pavement construction materials.
- CRC is typically widely available within metropolitan areas (and some regional areas), with a number of suppliers located within the vicinity of the Perth metropolitan area.
- The rigorous pre-acceptance and material processing controls, as well as batch testing requirements for CRC sourced from RtR accredited suppliers, results in a very low risk of contamination, with no reported asbestos exceedances at the time of writing since the current testing program commenced in financial year 2019/20.
- As a manufactured (crushed and screened) material, CRC can be produced to a relatively tight specification requirement, reducing variability in performance.
- CRC has demonstrated good performance in pavement applications.
- CRC is typically cost competitive with comparable materials.
- CRC is easy to place, moisture condition and compact.

- CRC can be trafficked unsealed for short periods with minimal risk of damage, potentially facilitating construction.

1.4 Structure

The following documents have been prepared:

- Practitioners Guideline.
- Technical Report (this report).

The content and relationship between each of these documents is summarised in Table 1.1.

Table 1.1: Structure of the documents

Document	Content
Practitioners Guideline	The Practitioners Guideline is presented in a user friendly format and provides key information needed for LG road managers to manage projects incorporating CRC.
Technical Report	The Technical Report containing the background research and supporting technical information for the Practitioners Guideline.

1.5 Scope and Methodology

The following scope of work was conducted to facilitate delivery of this report and the accompanying guideline:

- Literature review of WA, interstate and international publications, reports and specifications. The literature review mainly focused on information relevant to WA.
- Preparation of “recipe” based pavement designs incorporating CRC layers based on typical design traffic volumes and subgrade conditions for LG roads in WA.
- Discussion with various stakeholders from local and state government, industry bodies and CRC suppliers to understand their issues and requirements for the Practitioners Guideline and Technical Report.
- Preparation of the draft version of the Practitioners Guideline and Technical Report based on the findings of the literature review and stakeholder consultation for review.
- Presentation of the Practitioners Guideline and Technical Report contents in the form of a webinar to raise understanding of the information contained within the documents.

1.6 Limitations

This report is limited to the use of CRC in typical local government pavement applications with generally low to medium traffic volumes (less than about 10^7 ESAs). The information and pavement designs presented may not be appropriate for roads with very high traffic volumes, high proportions of heavy vehicles, or unique loading conditions such as industrial pavements (*i.e.* non-road legal axle configurations or loads). However, this does not necessarily imply that CRC would not be suitable in these cases.

2 Crushed Recycled Concrete

2.1 CRC Production

CRC is typically produced from concrete sourced from demolition sites or from left over material from concrete batch plants. The CRC source material is sorted to remove contaminants, crushed, screened and processed to comply with the requirements of the specification to which it is being produced (Austroads 2000). Ferrous and non-ferrous metals are also removed during this process, although the removal of non-ferrous materials requires specialist equipment.

Common materials used for CRC production are sourced from residential and commercial structures, structural and non-structural concrete, roads and hardstands. Materials used for construction of these assets, including deleterious materials (*e.g.* plastics, metals), can often be found in the source materials for CRC. CRC typically contains other materials such as roadbase, gravel, limestone, brick (both concrete and clay) roof tile (both concrete and clay), glass and can include small amounts of other undesirable materials, such as steel reinforcement, metals, plastics and organics.

2.2 Foreign Materials

As a significant portion of CRC is sourced from demolition sites it can contain foreign materials that were present at the CRC source. Some foreign materials do not affect the properties of the CRC significantly and are considered acceptable in modest amounts. Other foreign materials can have a deleterious impact on the properties of the CRC and must be limited.

2.2.1 Acceptable Foreign Materials

Foreign materials that may have negligible negative impact on the performance of CRC in pavement construction generally include unbound earthworks and pavement construction materials, plus crushed construction materials. Acceptable foreign materials may include:

- RAP.
- Crushed brick and tile.
- Basecourse and sub-base.
- Crushed glass.
- Ceramics.

These acceptable foreign materials may need to be crushed and screened (likely as part of CRC processing) to ensure compliance with the required specification.

2.2.2 Unacceptable Foreign Materials

Unacceptable foreign materials may negatively impact the performance of CRC when used in pavement construction due to a reduction in pavement stiffness or decomposition over time. Some unacceptable foreign materials, such as certain metals and asbestos, may pose a health hazard. Unacceptable foreign materials include:

- Low density materials (plastic, plaster).
- Organic matter.
- Inert or hazardous metals.
- Expansive materials (typically aluminium and gypsum).
- Asbestos (bound or fibrous).

The above unacceptable foreign materials may be allowed in small quantities depending on the CRC specification adopted. Further information on limits for asbestos and hydrocarbons is provided in the *Roads to Reuse Product Specification – Recycled Road Base and Recycled Drainage Rock* (Waste Authority WA, 2021) (RtR Specification).

At the time of writing, RtR accredited producers have not reported any asbestos exceedances against the RtR Specification requirements (Roads to Reuse | Waste Authority WA).

2.2.3 Sourcing

CRC that originates from demolition sites (as opposed to that sourced from excess concrete directly from concrete suppliers) can contain a range of materials, some of which maybe deleterious to performance (ARRB 2020). Adherence to appropriate specifications for thresholds on foreign materials are necessary to avoid negative consequences for CRC performance and the risk profile of the project. For example, MRWA has developed foreign material limits which are considered suitable for CRC used as sub-base under full depth asphalt pavements (MRWA 2023).

Excess deleterious foreign materials must be removed for the final product to comply with the relevant specification requirements.

The properties of the CRC source material will affect the properties of the resulting CRC. For example, recycled aggregate sourced from crushed high strength structural concrete may have different properties to that produced from non-structural concrete (Austroads 2022).

2.2.4 Example Specification Limits for CRC Composition

Foreign materials will be present in almost all CRC source material. Depending on the type of foreign materials, these may have detrimental effects on the properties of the CRC. Limits on foreign material content therefore need to be specified, and should account for the expected use of the CRC; for example higher limits may be acceptable in lower traffic situations.

As an example of how the foreign material limits for CRC can be specified for various projects, discussion of the PTA specification limits for CRC is provided. The PTA has developed Specification 8880-450-067 for the design and construction of Roads, Busways, Paths and Access Tracks (PTA, 2023), which includes a specification for the use of CRC in PTA infrastructure.

Table 5 of PTA (2023) specifies limits for various foreign materials in CRC. These are as follows:

- Asphalt (but not RAP): 15% for sub-base, 10% for basecourse.
- Low density materials (plaster, plastic, low density brick etc.): 1.5% for sub-base, 1.0% for basecourse.
- Organic matter (wood etc.) retained on a 4.75 mm Australian Standard sieve: 1.0% for sub-base, 0.5% for basecourse.
- Unacceptable high-density materials (inert metals, glass and ceramics) retained on a 4.75 mm Australian Standard sieve: 3% for sub-base, 2% for basecourse.
- Aluminium as a metal (non-oxidised): 0.001%.
- Asbestos and other hazardous materials: In accordance with the RtR Specification.

The PTA specification also allows a more diverse product to be accepted than MRWA (2023). This is because CRC used on PTA projects would typically be for lower traffic situations than CRC used on MRWA projects. The limits on various materials are:

- Crushed recycled concrete: minimum 55%, maximum 95%.
- Crushed granite roadbase, natural gravels with plasticity index less than 10% recovered from road pavements (basecourse): maximum 45%.

- Crushed granite roadbase, natural gravels and limestone recovered from road pavements (sub-base): maximum 45%.
- Crusher residue from manufacture of concrete aggregates: maximum 45%.
- High density fired clay brick and tile (sub-base): minimum 5%, maximum 45%.
- High density fired clay brick and tile (basecourse): minimum 5%, maximum 20%.

A notable difference between the PTA (2023) and MRWA (2023) specification limits for CRC composition is that the PTA (2023) specification allows a lower proportion of crushed concrete than the MRWA (2023) specification.

The PTA specification includes two grading curve limits for the particle size distribution of CRC to support use of material from multiple CRC suppliers. Limits for both 25 mm (basecourse) and 20 mm (sub-base) are included. Requirements for the reporting of UCS testing at 7 days and 28 days are included to assess the potential for the material to become bound.

2.3 General Properties of CRC

2.3.1 Overview

For the purpose of this report, CRC includes material that will be subject to rehydration of residual cement in the product, with behaviour in the long term similar to bound/lightly bound or modified materials as defined by Austroads (2017). Material with insufficient residual cement such that is does not undergo rehydration and become bound or modified may not experience the same issues as CRC (for example block cracking), and therefore the advice presented in this report may not be applicable.

Materials that do not undergo self-cementation can be specified in relation to performance properties; resistance to mechanical breakdown and structural strength, defined by resilient modulus as determined from repeat load triaxial testing, or soaked California bearing ratio (CBR). Classification tests such as particle size distribution, Atterberg limits and linear shrinkage can be applied to assess the consistency of these materials.

Materials with a higher percentage of residual cement, *i.e.* CRC, will rehydrate and become modified or bound over time. For these materials, UCS testing is required in addition to the above tests to assess the degree of recementation.

As CRC can be sourced from demolition sites, it may contain various proportions of non-cementitious foreign materials, such as crushed brick and tile, asphalt, sand and aggregates. A proportion of non-cementitious materials is allowed by most CRC specifications, although the allowable proportion can vary depending on the end use of the CRC (basecourse or sub-base, low or high traffic situation, *etc.*).

2.3.2 Physical Properties

ARRB (2020) defines the various components of CRC as follows:

- Primary Material – concrete. Recommended to comprise 90% of the final product in basecourse applications.
- Supplementary – brick, crushed stone, tiles and masonry. Acceptable in small to medium amounts for sub-base and small amounts for basecourse.
- Friable materials – plaster and clay lumps. Can be detrimental to performance, recommended to be minimised in basecourse applications.
- Foreign materials – rubber, plastic, paper, cloth, paint, wood and organic matter. Detrimental to performance.

- Bituminous materials – asphalt and sprayed seals. Acceptable in pavements which will not be stabilised with additional cement and not suitable if cement stabilisation is proposed. Can be stabilised with bituminous binders.

Compared to virgin quarried aggregates, CRC aggregates also may have a lower impact resistance, density and abrasion resistance. CRC may have around a 20% lower density than virgin aggregates, which can have a positive impact on transport of the material (Austroads 2022). CRC also has greater stiffness and strength than typical road construction materials for granular pavement applications. CRC pavements appear to have superior performance to virgin materials when moisture ingress occurs (ARRB 2022). CRC is also indicated to have higher bearing capacity and improved rut resistance compared with natural aggregates (Austroads 2022a).

There may be a risk of leaching of CRC when used in close proximity to water bodies due to the alkalinity of the material; however, this risk is considered to be low once the road pavement and surfacing layer has been laid (MRWA 2022).

VicRoads considers recycled material supplied in accordance with the specification requirements to be an equivalent product to quarried material (VicRoads 2023).

2.3.3 Particle Size Distribution

CRC is a manufactured (crushed) product and most road authorities require 100% of the material to pass a 26.5 mm Australian Standard sieve (refer Table 2.2), be well-graded with a relatively even distribution of particle sizes, and be produced to a relatively tight grading envelope. Provided the crushing and screening plant is set up appropriately, producers of CRC should not have significant issues achieving the required particle size distribution tolerances.

As for other granular pavement materials, the grading envelope is selected to ensure a good distribution of particle sizes such that a tight matrix of material is produced following compaction. The upper limit for material passing the 0.075 mm Australian Standard sieve is generally between about 10% to 15%, with lower limits typically between about 3% to 5%. This allows sufficient fine material to help bind the compacted CRC together and create a tight surface suitable for some trafficking during construction and application of the overlying layers.

2.3.4 Atterberg Limits and Linear Shrinkage

The Atterberg limits (liquid limit and plastic limit) and linear shrinkage of a material provide an indication or how the proportion of material passing a 0.425 mm Australian Standard sieve behave. Of particular interest for general specification of pavement materials is the liquid limit and linear shrinkage. The liquid limit defines the moisture content at which the material starts to behave more like a liquid than a solid, and the linear shrinkage defines the proportion of shrinkage a linear sample of material undergoes as it is dried back from its liquid limit.

As the porosity of CRC is typically higher than quarried materials, the liquid limit and plastic limit of CRC may be higher. The optimum moisture content of CRC can also be up to about 30% higher than a comparable quarried material due to the absorptive nature of the material (ARRB 2020). However, it must be noted that this does not necessarily indicate that the CRC will behave similarly to a higher plasticity material. There does not appear to be a strong correlation between the liquid limit of CRC and its performance in pavement construction (ARRB 2010), and some authorities, such as MRWA, do not include a liquid limit requirement in CRC specifications.

The linear shrinkage for CRC materials is generally very low and unlikely to cause significant issues with performance in pavements.

2.3.5 Resilient Modulus

Resilient Modulus is an important input into mechanistic pavement design and has the most significant effect on the design fatigue life of overlying asphalt layers. Increasing the resilient modulus of the granular pavement layers, which includes CRC, generally increases the fatigue life of the overlying asphalt. Resilient modulus is generally a more important parameter for higher traffic roads surfaced with thin asphalt and is unlikely to significantly affect the performance of lower traffic roads.

The resilient modulus required to be achieved by a CRC product will depend on the expected traffic volume and the layer in which CRC is used in the pavement. For example, a higher resilient modulus would generally be required for CRC basecourse compared with CRC sub-base due to the higher loading stresses which are present near the surface of the pavement. Repeat load triaxial testing of CRC samples indicates that resilient moduli in excess of 350 MPa are typically achievable (Section 2.4.2), with some results much higher, up to about 800 MPa. These are acceptable values for LG pavements and resilient modulus of CRC should not be of concern where all other specification requirements are achieved. For the purpose of pavement design of local government roads using CRC, it may generally be assumed that the required resilient modulus has been achieved where the CRC complies with the MRWA (2023), IPWEA/WALGA (2016) or PTA (2023) specification requirements.

CRC that contains a sufficient proportion of cement will tend to increase in resilient modulus over time as rehydration occurs. This process requires moisture to be present within the material and water is absorbed during the formation of cementitious bonds (about one part water for every three-parts residual cement).

2.3.6 Unconfined Compressive Strength

The UCS of a CRC sample provides an indication of the amount of cementation that has occurred at a given curing period by measuring the force required to crush the sample. The crushing of CRC can reactivate unhydrated cement which leads to recementation over time. UCS samples are typically cured for a period of time prior to testing, which provides an opportunity for strength gain to occur. For a homogenous CRC material, shorter curing times are generally associated with lower UCS results. It is important to note that the rate of recementation of CRC is much slower than virgin cement such as Type GP (general purpose) cement. If UCS testing is only conducted at relatively short curing periods, such as 7 days or even 28 days, it is likely that the long-term UCS of the material will be underestimated.

The UCS of a modified or bound material is related to the risk of shrinkage (block) cracking occurring. Materials with a higher UCS may have an increased risk of developing shrinkage cracks which can reflect through the wearing surface. For pavement materials modified with virgin cement, a 28-day UCS of 1.0 MPa is typically regarded as the limit above which the material may begin to act as a bound material with an increased risk of block cracking. However, CRC tends to gain strength at a slower rate than virgin materials modified with cement, and as such, 28 days may not be a sufficient curing time for UCS samples of CRC. It is noted that UCS testing with long curing times can be impractical for CRC suppliers due to the long lead time.

Austroads (2017) defines a modified material as having a maximum 28-day UCS of 1.0 MPa; however, it is noted that this is based on the inclusion of virgin cementitious binder and does not account for the typically slower rate of strength gain of CRC materials. CRC with a 28-day UCS below 1.0 MPa may have a UCS significantly above 1.0 MPa in the longer term.

While the UCS testing is considered important in assessing the properties of CRC, the use of relatively short-term UCS results to assess the risk of block cracking is not recommended due to the likelihood that the UCS will continue to increase in the long term.

2.3.7 Los Angeles Abrasion

The LA Abrasion assesses the degradation of aggregates by abrasion and impact by testing a sample of material in a rotating steel drum with a charge of steel balls. Materials with a low LA abrasion value are more resistant to erosion and impact than those with a high LA abrasion value.

The Micro Deval test, a less aggressive alternative to the LA abrasion test, has been recommended as an alternative. It follows the same principle as the LA abrasion test but uses lower mass steel balls in the tumbler, and the test is conducted in the presence of water. The Micro Deval test has been shown to have better correlation with performance of recycled materials than the LA abrasion test (ARRB, 2010).

2.3.8 California Bearing Ratio

The CBR is a common test used for assessment of pavement and subgrade materials due to its usefulness (ARRB, 2010). The test involves pressing a flat cylinder into a sample of compacted material, with the result compared to that of a high quality Californian crushed rock, which has a CBR of 100%. The test may be conducted using soaked or unsoaked conditions. Soaked conditions are typically used for pavement materials.

CBR requirements are typically not a concern for CRC, with soaked CBRs greater than 100% often achieved. Low soaked CBR may be indicative of incorrect MMDD testing, as CRC can have two peaks in the MMDD curve (ARRB, 2010).

It is noted that MRWA Specification 501 requires a minimum soaked CBR of 100% for CRC. This has not proven difficult to achieve in the author’s experience.

2.3.9 Behaviour During Construction and Workability

Workability refers to the general behaviour of pavement materials during placement and compaction. A workable material is generally easy to lay out, moisture condition (evenly distribute moisture to facilitate compaction), and compact. A material that is not workable typically requires more effort in the construction process, for example, a curing period prior to compaction to allow uniform distribution of moisture.

CRC can have a relatively high porosity and water absorption when compared to virgin aggregates, which may affect workability (Austroads 2022a). There have been some reported differences in workability of CRC compared with quarried crushed rock products due to the moisture-absorbing properties of CRC (Austroads 2000). However, another source indicates that CRC is a workable material that produces a tight surface finish (MRWA 2022).

Feedback from CRC Pilot Project trial sites indicated that the material was consistent, workable and easy to place, with no rework required during the trial. The completed CRC exhibited a well bound surface with a good mosaic that was suitable for heavy sweeping and application of a prime. The CRC had good resistance to damage from construction traffic (DWER 2020).

General feedback from contractors on projects the authors have been involved with indicates that CRC is typically a workable material and does not create significant construction issues. During construction of a CRC trial on Welshpool Road in Perth, it was noted that the surface withstood heavy turning traffic for 10 days prior to application of the wearing course. This traffic included road trains (ARRB 2010).

CRC can be a variable material and to help produce a more uniform material it may be beneficial to utilise a single source for CRC on a project (Austroads (2022a).

2.4 Laboratory Testing of CRC

2.4.1 ARRB (2010) Laboratory Testing Findings

ARRB (2010) conducted a review of multiple sources of CRC information from within Australia and internationally. The review noted the following with regard to laboratory testing and specification of CRC:

- If a CRC is known to break down during compaction, then producers of the material should target the coarser side of the specification limits.
- Cement-based fines present in the CRC can absorb and hold moisture in pore spaces, which can lead to high liquid limits being reported. The report recommended that liquid limit not be used for specifying CRC properties.

A summary of the pertinent findings from ARRB (2010) is presented in Table 2.1.

Table 2.1: Summary of CRC properties

Material Property	Typical Range of Results	Discussion of Findings
Liquid Limit	Mean: 34.5%	The liquid limit was relatively high and inferred to be affected by the presence of moisture trapped within the porous cement fines. It was recommended that the liquid limit not be used for specification of CRC.
Linear Shrinkage	Median: 0% Mean: 0.27%	The linear shrinkage of CRC was consistently low and an upper limit of 1.5% for linear shrinkage was recommended for basecourse; however, this could be increased for sub-base (no sub-base limit was recommended). A 7-day curing period was recommended for linear shrinkage testing.
Los Angeles Abrasion	95th percentile range: 36.3% to 42.2%	The Los Angeles abrasion test was not considered relevant to the specification for CRC as it is an impact test rather than an abrasion test. The Micro Deval test was suggested as an alternative for CRC. The Micro Deval test follows the same principal as the Los Angeles abrasion test but uses lower mass steel balls in the tumbler. It also includes water which would help identify materials that could break down when wet.
Maximum Dry Compressive Strength	95th percentile range: 0.75 MPa to 0.93 MPa	The MDCS test did not appear to correlate with observed performance of CRC. MDCS values on CRC samples were typically low (about 0.8 MPa), which indicates the material may be susceptible to ravelling under traffic, however performance of unsealed CRC under heavy traffic was reported to be good.
Modified Maximum Dry Density and Optimum Moisture Content	1.79 t/m^3 to 2.01 t/m^3 95th percentile range: 1.89 t/m^3 to 1.91 t/m^3 OMC: 9.8% to 16.7%	The OMC of CRC was found to be difficult to predict as the moisture content/dry density curves were relatively flat and typically contained a second lower peak density at a moisture content above OMC. The importance of including the zero air voids line on the density chart was noted to check that the curve is approaching a tangent to the zero air voids line at the maximum density. It is noted that OMC values appeared to be around 10% to 13% for the CRC samples tested. Values significantly above this range should be investigated and may be erroneous.
Soaked California Bearing Ratio	Minimum: 40% 95th percentile range: 121% to 171%	Soaked CBR testing returned consistently high results but the importance of confirming the correct OMC and MDD to facilitate compaction of the CBR samples was highlighted. Isolated low soaked CBR values were reported but all appeared to have been compacted at an unrealistically high moisture content using the incorrect modified maximum dry density.
Unconfined Compressive Strength	Not tested	UCS testing was recommended to form part of CRC material specifications to manage the risk of shrinkage cracking, but did not form part of the scope of testing for the report. It was noted that 28 days may not be sufficient UCS curing time for CRC samples and that further testing at longer curing times was required.
Resilient Modulus	320 MPa to >1,000 MPa	There is significant range in the resilient modulus of CRC, with moisture content and curing time in particular having a significant impact on the results. Repeated load triaxial testing indicated a clear relationship between resilient modulus and curing time, with an increase in resilient modulus observed with increasing curing time up to 28 days.
Friction Angle and Cohesion	Friction Angle: 56.9° (1 day cure) to 62.6° (28 day cure) Cohesion: 58.4 kPa (1 day cure) to 86.5 kPa (28 day cure)	The friction angle of the CRC was very high, typically above 50° at curing periods of between 1 day and 28 days. The testing indicated that CRC has good resistance to deformation due to shear failure. However, friction angle and cohesion were not recommended to form part of the specification of CRC as these properties can be controlled through other more practical tests such as soaked CBR and grading.

Source: ARRB (2010)

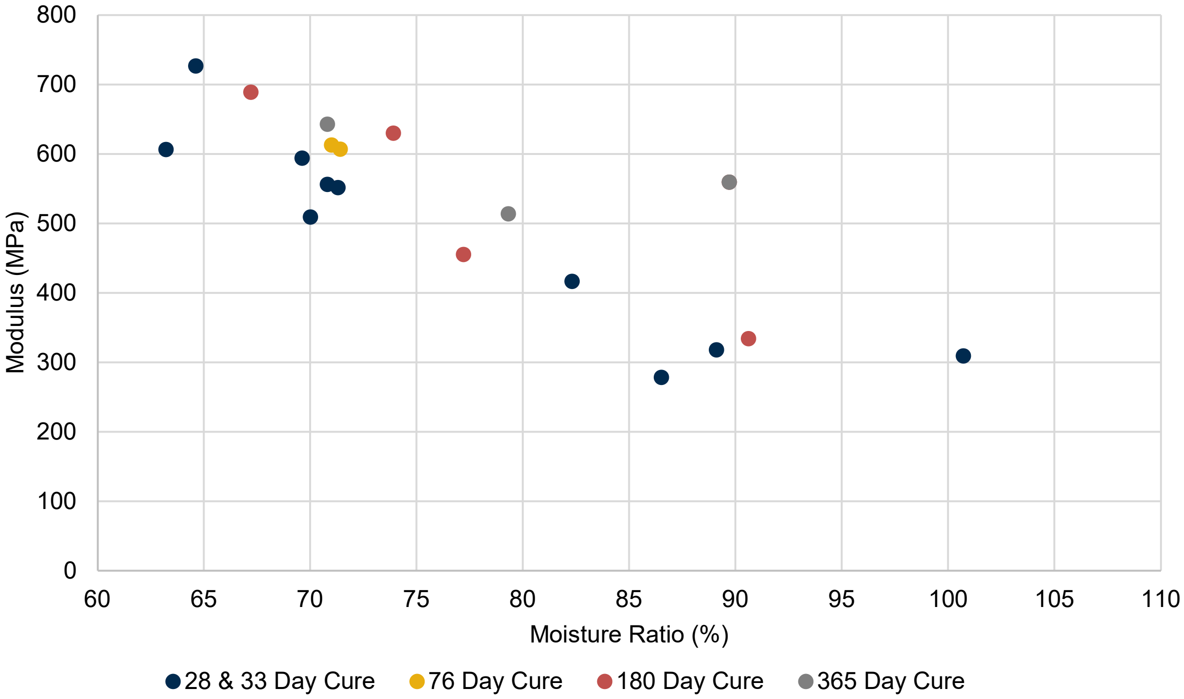
2.4.2 Resilient Modulus

The resilient modulus of CRC will depend on the source material properties; however, can range from about 350 MPa at relatively high moisture content, to about 900 MPa as the moisture content reduces (Leek 2011).

DIT (previously Transport SA) also undertook testing which indicated that the resilient modulus of CRC exceeded that of quarried road base. Resilient moduli of between about 600 MPa to 700 MPa were recorded for CRC, compared with about 200 MPa to 400 MPa for quarried road base (ARRB 2010). The testing was conducted at around 50% to 60% of MOMC.

MRWA (2020) reported resilient moduli ranging from about 300 MPa at about 85% to 100% of MOMC up to over 700 MPa at about 65% of MOMC. A clear relationship between resilient modulus and moisture content was observed, with modulus increasing with reducing moisture content. Figure 2.1 shows the relationship between resilient modulus and moisture conditions using the results from MRWA (2020) when tested at basecourse octahedral shear stress and mean normal stress conditions of 120 kPa and 240 kPa respectively.

Figure 2.1: CRC resilient modulus vs moisture content



Source: WSP (adopted from MRWA (2020))

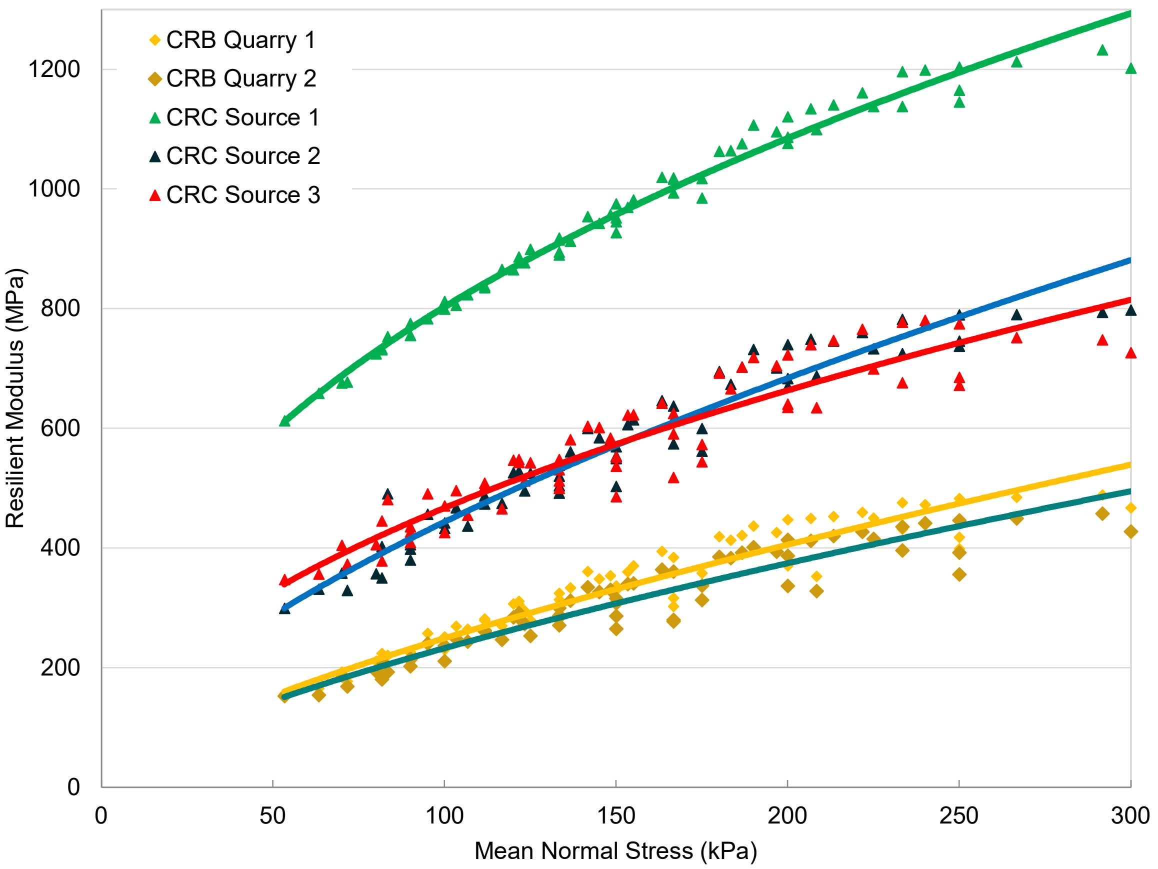
Testing on various CRC materials was undertaken at Curtin University and compared to CRB (ARRB 2010). Samples of three sources of CRC and two sources of CRB were tested at 60% and 80% of MOMC. The samples were prepared at MOMC, and oven dried to achieve the required moisture content, before being wrapped and left for 28 days for moisture to distribute though the samples. As it is accepted that cement hydration continues during this time, the results of testing for the CRC samples are influenced by both friction angle and chemical bonding, the second of which does not occur in the CRB.

The CRC from Source 1 was sourced from a supplier who undertakes demolition works and was inferred to have a higher concrete content than the other two sources; however, the exact makeup is unknown.

Figure 2.2 and Figure 2.3 plot the results of resilient modulus (i.e. material stiffness) against the mean normal stress applied to the material during testing. From Figure 2.2 and Figure 2.3 it can be seen that the modulus of the CRC sources is considerably higher than that of the CRB. The CRC samples tested do indicate stress dependency, with the modulus of the samples increasing with increasing normal stress.

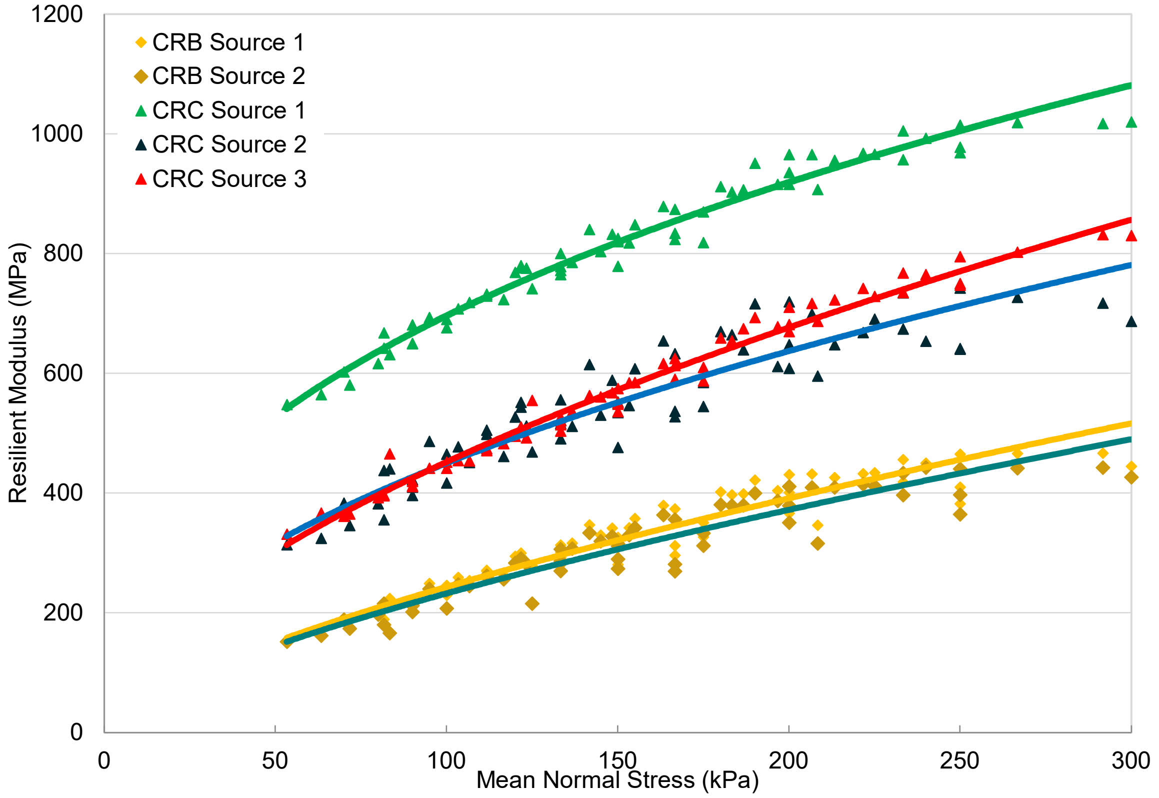
In addition, the concrete proportion within the CRC has an apparent effect on the modulus of the material, with modulus generally increasing with increasing concrete content, but no conclusive relationship was derived.

Figure 2.2: Resilient modulus vs mean normal stress at 60% of optimum moisture content



Source: ARRB (2010)

Figure 2.3: Resilient modulus vs mean normal stress at 80% of optimum moisture content



Source: ARRB (2010)

It should be noted that the Source 1 supplier is the only one of the three engaged during this work still operating as a recycler of demolition materials, but the CRC products available currently are typically different to those available previously. At the time the testing presented in this section was conducted, the CRC material was contained a significant proportion of concrete, but due to the company now receiving a greater proportion of material from other sources not associated with its own demolition, the concrete proportion in the CRC products has reduced.

2.5 CRC Impurities that Affect Performance

As outlined above, CRC may contain impurities that could affect the performance of the material when used in pavement construction. These impurities may affect the stiffness of the pavement, or its ability to achieve the relevant specification requirements.

Most impurities are difficult to remove from the waste stream and it is important that they be controlled at the CRC source.

Contaminants that do not affect CRC performance significantly at low contents such as heavy metals or asbestos must also be controlled but are not discussed further in this section.

2.5.1 Metallic Aluminium

Metallic aluminium may be present in the source material for CRC due to its use in items such as aluminium window frames and pop-rivets. Metallic aluminium can expand significantly in volume when present in CRC, as the high-pH environment affects the protective coating of aluminium oxide that typically forms when the metal corrodes. This allows further corrosion to occur, and the pockets of metallic aluminium can fully oxidise. Expansion of the aluminium oxide can cause lifting of the overlying wearing course if it is present near the upper surface of the pavement.

Aluminium compounds are also a byproduct of thermite welding of railway tracks. Care should be exercised if including rail ballast in CRC products.

Metallic aluminium can be difficult to remove from CRC as it is not magnetic (non-ferrous). While specialised eddy current separators can be used to remove non-ferrous metals during processing of CRC, it is generally more economic to control the amount of aluminium present in the source material.

At the date of publishing this report at least one RtR accredited CRC supplier had indicated they were able to remove non-ferrous metals from CRC using eddy current separation.

2.5.2 Gypsum

Gypsum may be present in the source material for CRC due to its use in plasterboard or gyprock. Similarly to aluminium, gypsum can expand in the high-pH environment present in CRC and lead to lifting of the wearing course if it is located near the pavement surface.

It is impractical to remove gypsum from CRC once it has been processed and therefore must be controlled at the CRC source.

2.5.3 Effect of Aluminium and Gypsum

Where aluminium and gypsum are present in CRC near the surface and expand, they cause localised lifting of the surface which manifests as a blister or dome. The domes formed by expansive aluminium and gypsum may not necessarily be an issue for low traffic/low speed roads and may even be controlled to some degree by rolling from traffic. However, they may present a safety issue if they form where CRC has been used as a basecourse for areas trafficked by pedestrians or cyclists only, such as paths or playing surfaces (tennis/ basketball/netball courts etc).

Figure 2.4 shows examples of blistering occurring in a public car park and on a principal shared path.

Figure 2.4: Blistering of surface above a CRC pavement (left – car park, right – shared path)

Source: Colin Leek/Dale Screech

2.5.4 Low Density Materials

The presence of significant quantities of low density materials such as plastic, plaster, etc. may affect the stiffness of the CRC pavement and reduce the effectiveness of compaction. In particular, plastic may deform and rebound under transient applied loads (such as during compaction), reducing the density which can be achieved.

Low density materials such as plaster also have relatively low strength and will reduce the stiffness of the CRC pavement.

2.6 Specification Overview

Various Australian road authority specifications for CRC have been reviewed. A summary of the pertinent specification limits is presented in Table 2.2. The relevant specification requirements have been summarised to facilitate presentation of the data and not all material types in the specifications have been summarised. Where multiple nominal particle sizes are provided within specifications, the smallest particle size has been presented; typically this is referred to as a 20 mm material within the relevant specification (maximum particle size passing an Australian Standard 26.5 mm sieve).

Table 2.2: Summary of Specification Requirements for CRC

Specification	Total Allowable Design Traffic (ESAs)	Allowable Pavement Layer	Maximum Particle Size (mm)(1)	Fines Content(2)	Liquid Limit (%)	Linear Shrinkage (%)	Soaked CBR (%)	UCS (MPa, 7 days unless noted)
Western Australian Specifications								
IPWEA/WALGA Specification for the Supply of Recycled Road Base	Refer Specification(3)	Basecourse or sub-base	26.5	3-11	-	0.2-1.5 (basecourse) 0.2-4.0 (sub-base)	>100 (98% MMDD)	0.2-1.0 (basecourse) 0.2-2.0 (sub-base)
MRWA Specification 501 – Pavements	N/A	Sub-base (FDA only)	26.5	3-11	-	<4.0	>100 (94% MMDD)	<1.0
Public Transport Authority (WA)	N/A	Basecourse or sub-base	26.5	4-10 (basecourse) 4-14 (sub-base)	-	<1.5 (basecourse) <5.0 (sub-base)	>80 (basecourse, 98% MMDD) >60 (sub-base, 96% MMDD)	<1.5 (28 days)
Interstate Specifications								
DIT Master Specification RD-PV-S1 Supply of Pavement Materials	N/A	Basecourse or sub-base	26.5 (typical)	5-11 (basecourse) 4-14 (sub-base)	<25 (basecourse) <28 (sub-base)	<3 (basecourse) <4 (sub-base)	-	-
IPWEA (NSW) Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage	$>1 \times 10^6$ (Class R1) $<1 \times 10^6$ (Class R2)	Basecourse or sub-base	26.5	5-15	<27	-	N/A (Class R1) >60 (Class R2)	<1.5 (28 days)
TfNSW QA Specification 3051 – Granular Pavement Base and Sub-base Materials	$>4 \times 10^6$ (Class 1 base) $<4 \times 10^6$ (Class 2 base) Any (sub-base)	Basecourse or sub-base	26.5 (basecourse) 26.5 or 40 (sub-base)	3-7 (basecourse) 2-10 (sub-base)	<20 (Class 1 base) <23 (Class 2 base) <23 (sub-base)	-	-	<1.0
TMR Technical Specification MRTS05 Unbound Pavements(4)	<500 ESAs/day (basecourse only)	Basecourse or sub-base	26.5	5-11 (basecourse) 3-11 (sub-base)	<35 (typical)	1.0-3.5 (basecourse) 1.5-4.5 (sub-base)	>80 (basecourse, 100% MMDD) >60 (sub-base, 100% MDD)	<0.7
VicRoads Section 820 – Crushed Concrete for Pavement Sub-base and Light Duty Base (now superseded)(5)	"Light duty" (basecourse) N/A (sub-base)	Basecourse or sub-base	26.5	5-9 (basecourse) 2-10 (sub-base)	<35	-	>80 (basecourse, 98% MMDD) >80 (sub-base, 98% MMDD)	-

1. Maximum particle size based on largest allowed Australian Standard sieve within each specification.
2. Fines content based on allowable range passing an Australian Standard 0.075 mm sieve.
3. Allowable traffic volume depends on the pavement profile. Refer to Table 1 within the relevant specification.
4. Excludes Sub-type 2.5.
5. VicRoads now considers CRC to be equivalent to virgin materials and has included CRC within other pavement material specifications. Section 820 was selected as it was specific to CRC.

2.7 Identified Risks

CRC has been used in both unbound and bound pavements (Austroads 2022). MRWA considers CRC suitable for use as sub-base under FDA pavements. It is high strength, durable, and its stiffness increases over time such that it behaves similarly to lightly bound materials (MRWA 2022). There can be significant variation in the amount of recementation of CRC, which depends on the age and cement content of the source materials (MRWA 2022).

Depending on the source of concrete for production of CRC, it may behave as either a bound, unbound or modified material. When conducting pavement design incorporating CRC layers, both of these behaviours should be considered (L5D 2021). TMR allows the use of CRC in both bound and unbound pavements (TMR 2020).

The potential for CRC materials to recement and undergo shrinkage from rehydration of the residual cement needs to be considered when using the material. The use of CRC in sub-base applications, or blending with other non-cementitious materials, can help manage the risk of shrinkage cracking reflecting through the surfacing (ARRB 2022). Cracking of cemented materials can allow moisture infiltration if it reflects through the wearing course, which can increase the rate of deterioration of a pavement through moisture ingress, pumping and erosion (Austroads 2017).

Some thin asphalt surfaced CRC pavements have developed block (shrinkage) cracking in the wearing course between three and 10 years following construction. CRC pavements also present a fatigue cracking risk if used as a basecourse under heavy traffic loading (DWER 2020).

Blistering (also referred to as “domes” or “popping”) has occurred on some pavements where CRC has been used as basecourse. The underlying cause was identified to be pieces of aluminium (*e.g.* rivets) or other expansive materials in the CRC expanding sufficiently to lift the wearing course (DWER 2020). Other materials, such as pyrite and dolomite, can also react to form expansive materials (SASA).

A summary of risks associated with CRC as identified by MRWA is provided in Table 2.3.

Table 2.3: Risks associated with CRC

Risk	Cause	MRWA Mitigation Measures
Cracking	Reactivation of cement	Use as sub-base under Full Depth Asphalt. Do not use as basecourse under heavy traffic. Apply geofabric seal if used as basecourse.
Popping	Expansive impurities (e.g. aluminium, gypsum)	None identified (steel is removed) - remove and replace if occurs
Hazardous Contaminants	Asbestos and other hazardous materials not removed in demolition	Refer to RtR Specification and Guidelines Robust management systems Supplier end product testing DWER independent audit testing
pH	Reactivation of cement	Do not use near wetlands or groundwater sources

Source: MRWA (2022)

3 Roads to Reuse Specification

The Western Australian Government has developed the RtR Specification which includes sampling, testing and auditing requirements and the requirement to produce a material acceptance and sampling plan to ensure that materials produced meet specifications designed to protect human health and the environment. These include requirements such as:

- Pre-acceptance and operational controls, such as identifying source material and contamination risks associated with the material's source, inspections, and non-acceptance or removal of non-permitted materials.
- Product sampling, testing and analysis.
- Auditing.
- Record keeping.

Depending on the source of the material and the previous use(s) of the source site, non-accredited C&D material may include contaminants such as pesticides, asbestos, and heavy metals. The high alkalinity (pH) of CRC has a propensity to leach potential contaminants such as heavy metals into the surrounding soil and drainage.

Acquiring CRC from a RtR accredited supplier provides assurance that the material has been produced to a certified standard that ensures risks associated with material use have been assessed and managed. It is recommended that only RtR accredited materials, sourced from a RtR accredited supplier, be used. A current list of accredited RtR suppliers is available on the Waste Authority WA website (Roads to Reuse | Waste Authority WA).

It must be noted that the engineering properties of recovered materials are not within the scope of the RtR Specification. Producers of materials may also need to adhere to a design specification, such as the IPWEA/WALGA Specification for the Supply of Recycled Road Base (IPWEA/WALGA 2016), to assess suitability for use in pavement construction.

The RtR Specification also outlines the conditions of use which manage the risks associated with use of the material. The March 2021 revision of the RtR Specification (current at the time of writing) states that:

"For the purposes of the Roads to Reuse program:

- *Road base containing concrete, and with a pH greater than 9, may only be used under bituminous seal or asphalt.*
- *Recycled products should not be used within 0.5 m of the maximum groundwater level.*
- *The use of recycled road base is not to occur within the following locations within public drinking water source areas (PDWSAs):*
  - *Priority 1 (P1) areas*
  - *Wellhead protection zones*
  - *Reservoir protection zones."*

Further information on PDWSAs is provided in the RtR Specification.

4 Case Studies

4.1 Gilmore Avenue

Cocks *et al* (2017) includes data on Gilmore Ave in City of Kwinana where a pavement trial of CRC basecourse over limestone sub-base was undertaken in 2003 as a trial between the City of Kwinana and MRWA. Pavement sections were constructed comprising the pavement profiles outlined in Table 4.1.

Table 4.1: Gilmore Avenue CRC trial sections

Section	Trial Section	Control Section
Surfacing	30 mm DGA	30 mm DGA
Basecourse	125 mm CRC	125 mm CRB
Sub-base	150 mm limestone	150 mm limestone

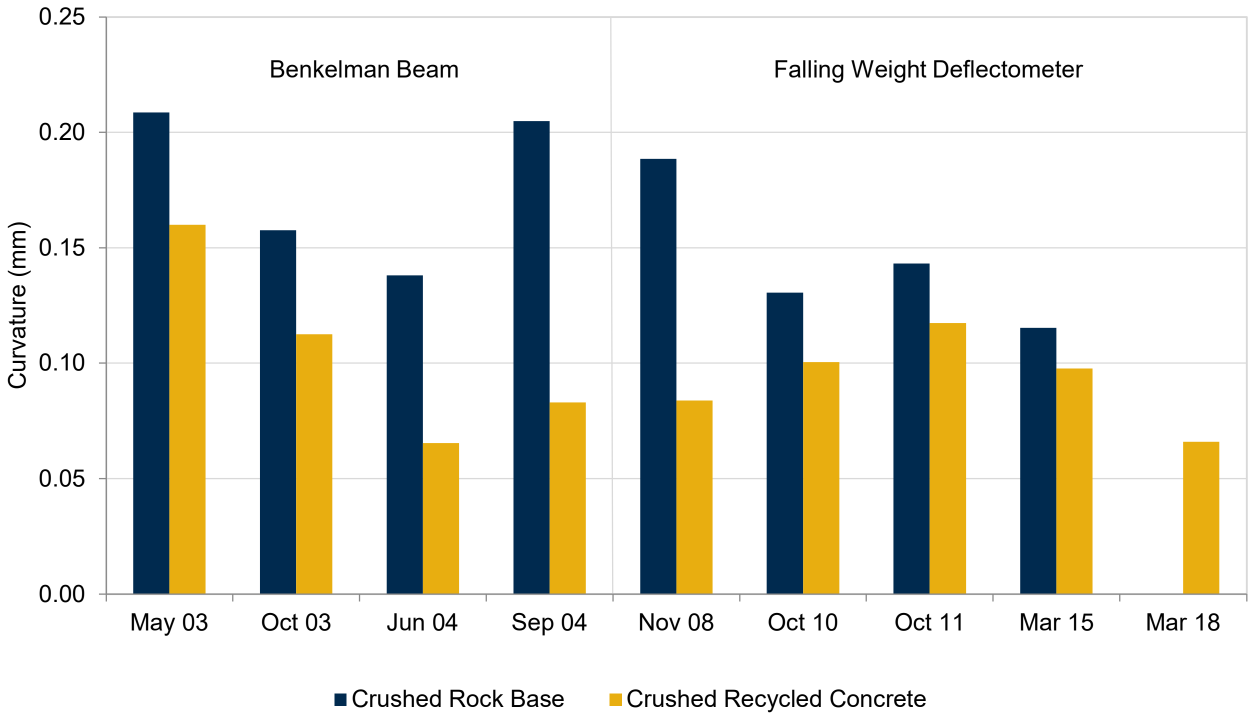
Source: Cocks *et al* (2017)

Both sections were constructed adjacent to each other and subjected to the same traffic. The design traffic was 7.0 × 10^6 ESAs (Cocks *et al*, 2017).

Anecdotal evidence indicates that no prime or seal was applied below the asphalt wearing course.

Testing to assess the stiffness of the constructed pavement trials was initially undertaken using the Benkelman Beam (prior to 2004), and later using the FWD (from 2008). The Benkelman Beam and FWD curvature results are presented in Figure 4.1.

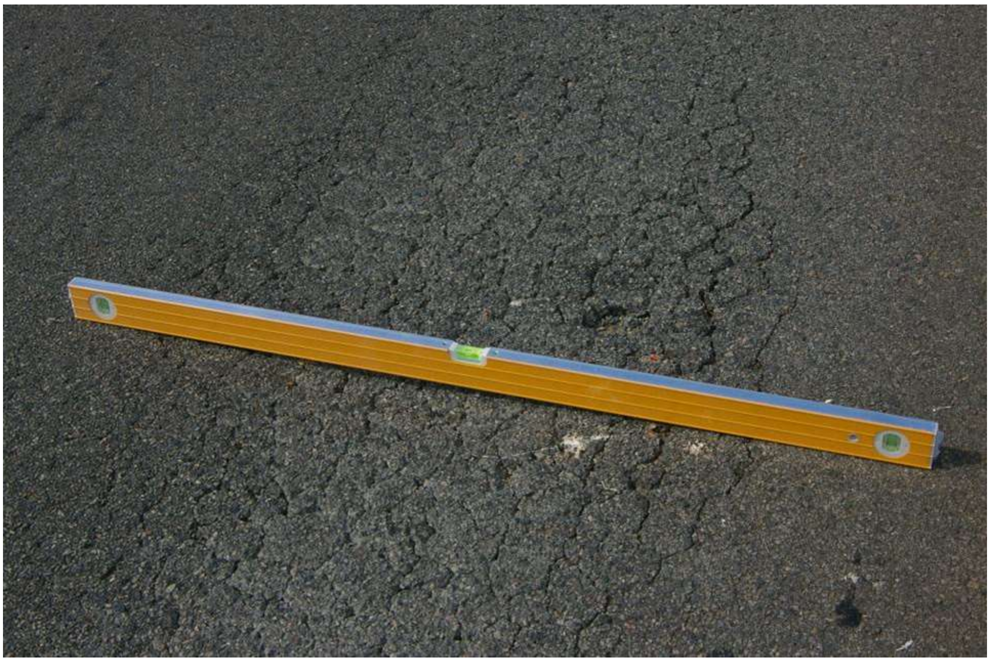
Figure 4.1: Gilmore Avenue curvature results (90th percentile at 566 kPa drop stress)



Source: Cocks *et al* (2017)

By 2010, the Gilmore Ave control section constructed using CRB had extensive rutting and fatigue cracking as shown in Figure 4.2 and was reconstructed in 2015.

Figure 4.2: Fatigue cracking and rutting of Gilmore Avenue CRB control section



Source: Colin Leek

Around 2011, the CRC section had developed minor hairline cracks as shown in Figure 4.3.

Figure 4.3: Hairline cracking in the CRC section on Gilmore Avenue

Source: Colin Leek

The CRC section performed better than the CRB control section, and in 2016 was still in good condition with a few transverse (shrinkage) cracks similar to those photographed in 2011. However, by 2018, the CRC section was also seriously distressed (Figure 4.4) and was stabilised using foamed bitumen in 2019.

FWD testing conducted around the time failure of the CRC section was observed indicate a relatively stiff pavement, with 90th percentile curvatures around 0.08 mm recorded. The FWD results indicate a stiff pavement but do not appear to have identified the cracking in the surfacing and basecourse.

Figure 4.4: Failed section of CRC on Gilmore Avenue in 2018

Source: Colin Leek

Based on the length of time of the CRC section was in place and the available traffic data, an expected 2×10^6 ESAs may have trafficked the CRC trial pavement. If the pavement was designed using a modulus for the CRC of 2,000 MPa, then the expected pavement life would only be about 110 ESAs. Adjusting the design modulus of the CRC layer or sub-base does not increase the design pavement life significantly (typically below 10^3 ESAs). This suggests that the life of some CRC pavements may significantly exceed the life indicated by the design.

The findings of the Gilmore Avenue trial indicate that:

- The CRC pavement was generally stiffer than the CRB pavement, based on the FWD curvature results.
- The CRC section had a longer life than the CRB section, with respect to cracking/fatigue of the asphalt wearing course.
- Shrinkage cracking may occur within CRC pavements.
- Failed CRC pavements may still be relatively stiff, as evidenced by low FWD deflection and curvature. A visual assessment is required to provide an accurate assessment of pavement condition.

4.2 Welshpool Road

Cocks *et al* (2017) includes data on Welshpool Road within the City of Canning, where a trial of CRC was undertaken in 2008. Four sections were constructed as outlined in Table 4.2. All sections were surfaced with a double/double bitumen emulsion waterproofing seal and 30 mm thickness of dense graded asphalt.

The design traffic for Welshpool Road was 2×10^7 ESAs.

Table 4.2: Welshpool Road CRC trial sections

Section	1 (control)	2	3	4
Basecourse Thickness	150 mm CRB	400 mm CRC(2)	150 mm CRC(1)	400 mm CRC(1)
Basecourse Nominal Size	20 mm	25 mm	25 mm	25 mm
Sub-base Thickness	250 mm CRC(2)	-	250 mm CRC(2)	-
Sub-base Nominal Size	25 mm	-	50 mm	-

1. CRC sourced from straight concrete with essentially no other materials present (*e.g.* aggregates, crushed bricks, *etc*.)
2. Comingled CRC which contains a significant (but unknown) portion of other non-cementitious allowable materials.

Source: Cocks *et al* (2017)

It is important to note that these sections were all constructed with an initial 250 mm layer followed by a 150 mm layer with the first layer allowed to dry back before the second layer was constructed. This may not have achieved a good bond between the CRC layers for Trial Sections 2 and 4, which is important to optimise the fatigue life of CRC basecourse (this is further discussed in Section 8.4). Trial Sections 3 and 4 which were constructed with CRC (straight concrete, not comingled) were showing considerable distress when visually assessed by one of the authors (Colin Leek) in 2023. It is noted that the straight concrete CRC sections (Trial Sections 3 and 4) have much lower curvature than the comingled CRC (Trial Section 2), and the control section with a CRB base (Trial Section 1), indicating higher stiffness. It is also noted that the comingled CRC (Trial Section 2) shows a higher stiffness than the CRB (Trial Section 1), and was showing no significant signs of distress when visually assessed by one of the authors in 2023. Photos of the straight CRC trial sections (Trial Sections 3 and 4) of Welshpool Road taken in 2023 are provided in Figure 4.5.

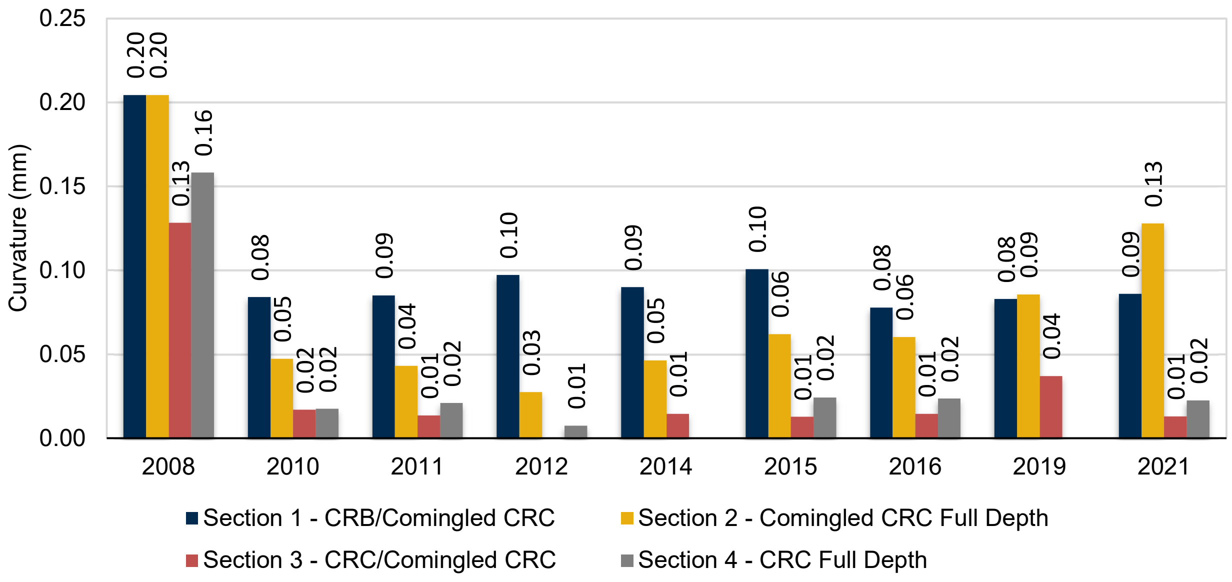
Figure 4.5: Photos of straight CRC Trial Sections 3 and 4 of Welshpool Road (taken in 2023)

Source: Colin Leek

The curvature results from FWD testing conducted on the trial sections are shown in Figure 4.6. The FWD testing was conducted at a target drop stress of 700 kPa and has been linearly adjusted to a drop stress of 566 kPa. The CRB basecourse section (Trial Section 1) was intended to be a control section; however, the inclusion of CRC sub-base appears to have improved the stiffness of the pavement compared with typical unbound granular sub-base materials. FWD curvatures for the control section (Trial Section 1) appear to be lower than typically achieved using CRB sourced from the Perth region, where values closer to about 0.15 mm would be expected.

The CRB trial section appeared to take longer to achieve a stable stiffness than the CRC sections, with an initial relatively high curvature of 0.25 mm (at 700 kPa drop stress, 0.20 mm linearly adjusted to 566 kPa drop stress) at the time of construction reducing to the range of about 0.08 mm to 0.10 mm over time. The CRC sections show relatively low curvatures during the early life of the pavement (typically below 0.05 mm), increasing as the surfacing cracks and the pavement ages.

Figure 4.6: Welshpool Road CRC trial sections FWD curvature data (linearly adjusted from 700 kPa to 566 kPa FWD drop stress)



Source: Cocks *et al* (2017)

The findings of the Welshpool Road trial indicate that:

- CRC and comingled CRC based material appears to be a suitable sub-base for heavy traffic loadings.
- CRC and comingled CRC based materials may not perform as well as CRB when used as a basecourse layer under heavier traffic loading due to the risk of fatigue of the CRC layer.
- CRC materials may not perform well under heavy traffic loading if the base layer is not structurally designed as a bound layer. Thinner overall pavements may be possible (depending on traffic and subgrade conditions), but base thickness must be designed using the mechanistic-empirical method (*i.e.* CIRCLY) and may need to be thicker than the empirical method indicates is required.

The above findings are not necessarily applicable to lower traffic roads where fatigue of the CRC layers may not be the failure mechanism.

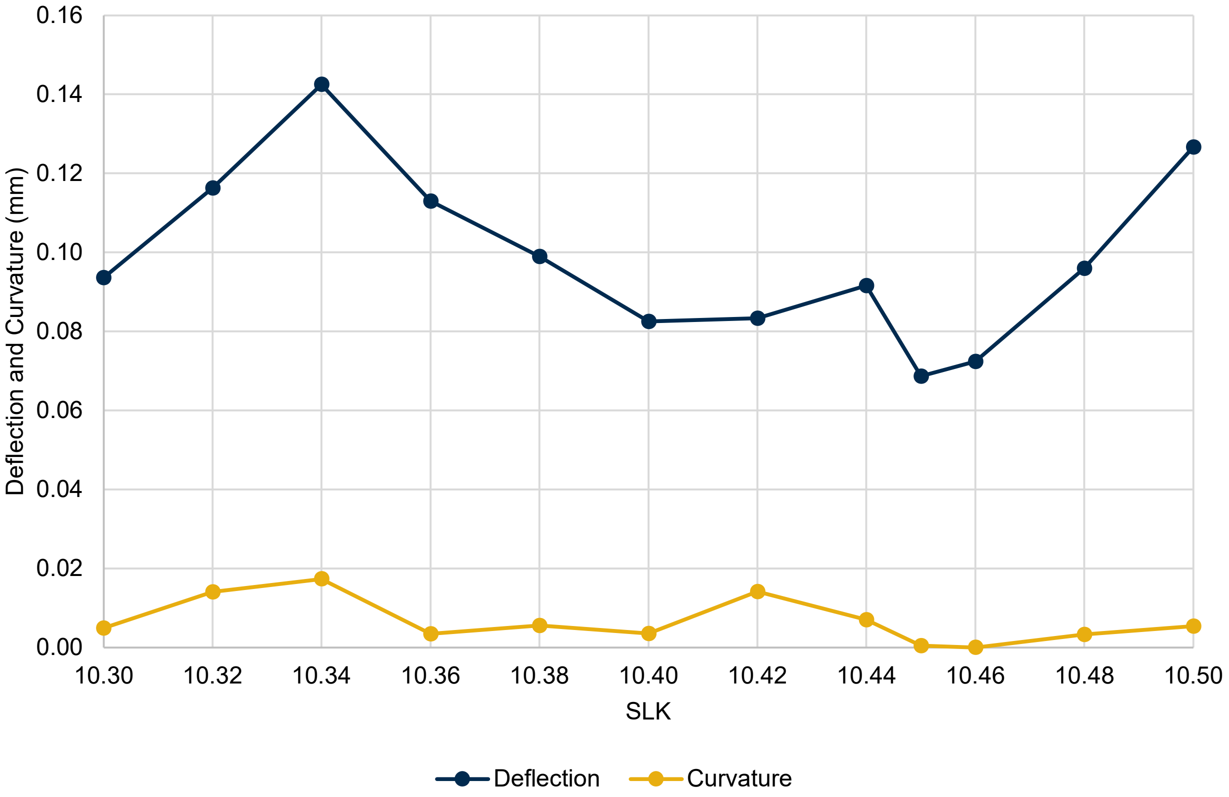
4.3 Nicholson Road

In 2008, Nicholson Road between Acourt Road and Clifton Road Canning Vale was duplicated to create a four-lane divided road, with a new northbound carriageway constructed. According to published traffic data for 2019/20 (the most recent year available), the northbound carriageway experienced traffic volumes of 12,317 vehicles per day with 6.5% heavy vehicles (design traffic loading of 2.2×10^7 ESAs).

CRC was used as a basecourse and sub-base and was indicated to have a high crushed concrete component. During construction, the CRC sub-base layer was compacted and allowed to dry back before the CRC basecourse layer was constructed. As outlined in Section 7.4.2, this may reduce the fatigue life of the pavement compared to construction with well-bonded sub-base and basecourse layers. The layer thicknesses were 250 mm for the sub-base and 150 mm for the basecourse.

FWD testing was undertaken at a drop stress of 700 kPa on a 200 m portion of CRC between SLK 10.3 and SLK 10.5 in December 2021, with the deflection and curvature values provided in Figure 4.7.

Figure 4.7: Nicholson Road Northbound deflection and curvature (December 2021, linearly adjusted from 700 kPa to 566 kPa FWD drop stress)



Source: Colin Leek

It can be seen that the deflection and curvature values are quite low. The mean curvature was less than 0.01 mm at a 700 kPa FWD drop stress, which indicates a high modulus basecourse. However, the pavement condition was deteriorating, with block cracking and pumping of fines evident from a visual assessment (Figure 4.8). The pavement may require rehabilitation in the near term, despite being only 14 years old when the photos in Figure 4.8 were taken.

The photos in Figure 4.8 were taken about two months after the FWD testing, and it could be assumed that the pavement condition at the time of FWD testing was similar to that indicated by the photos. It is noted that FWD results alone cannot be used to assess performance of a CRC pavement, as typically the higher-stiffness (*i.e.* lower curvature) pavements may be more likely to block crack.

It is hypothesised that the CRC sub-base and basecourse layers have not bonded and are acting as two individual layers, and that the basecourse layer has suffered fatigue failure. However, due to the individual blocks of CRC remaining stiff, on a stiff CRC sub-base, the curvature remains low.

Figure 4.8: Nicholson Road pavement condition (photos taken February 2022)

Source: Colin Leek

The findings of the Nicholson Road trial indicate that:

- The CRC pavement was generally stiff, based on the FWD curvature results.
- Bonding of pavement layers is important to optimise the fatigue performance where CRC basecourse is used.
- Shrinkage cracking may occur within CRC pavements.
- Failed CRC pavements may still be relatively stiff, as evidenced by low FWD deflection and curvature. A visual assessment is required to provide an accurate assessment of pavement condition.

4.4 Warton Road

Around the same time that the City of Canning was constructing Nicholson Road (Section 4.3), the City of Gosnells undertook the construction of a section of Warton Road with CRC basecourse. The pavement design for Warton Road was 350 mm limestone sub-base with 200 mm CRC basecourse and 30 mm dense graded asphalt. The actual constructed thickness of the CRC basecourse was slightly greater and averaged around 220 mm. The traffic loading on Warton Road in 2019/20 was 22,867 AADT with 4.5% heavy vehicles (both directions). The design traffic used for pavement design is not known to the authors.

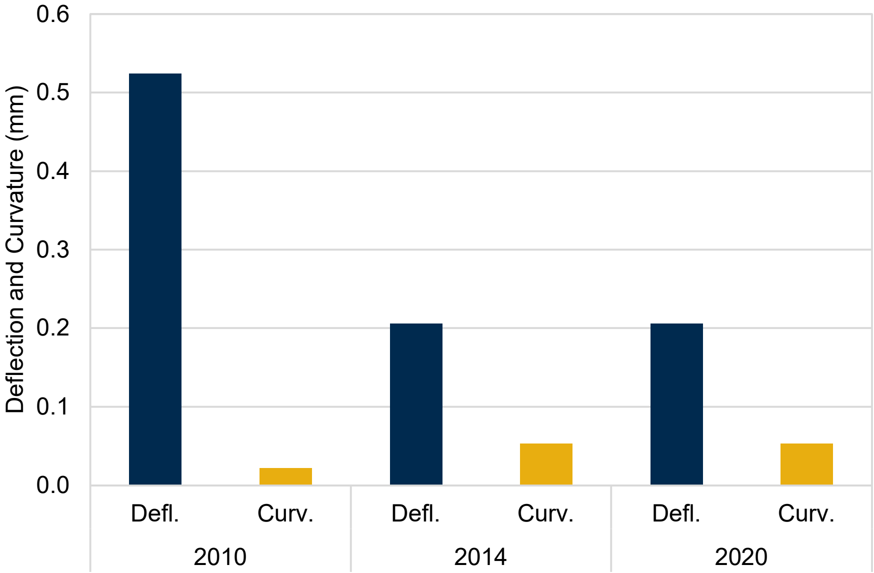
The City of Gosnells allowed sections of the pavement to be extracted for research purposes, and based on the appearance of the extracted pavement it is inferred that the CRC basecourse has become bound. Figure 4.9 shows well-cemented blocks of CRC basecourse which had been saw cut and removed from the pavement.

FWD testing was undertaken on three occasions at a target drop stress of 566 kPa as shown in Figure 4.10. The testing shows a marked reduction in deflection within the first few years of pavement life but a corresponding increase in curvature. The increase is not considered to be statistically significant due to the very low magnitudes of curvature measured.

Figure 4.9: Warton Road CRC basecourse sampling

Source: Colin Leek

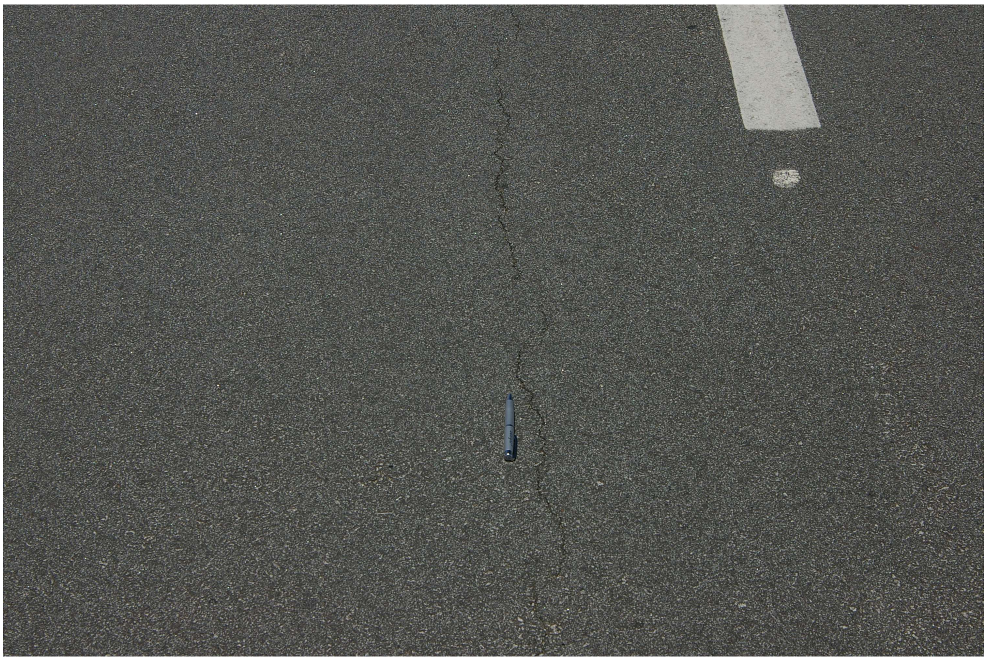
Figure 4.10: Deflection and curvature values from FWD testing on Warton Road



Source: Colin Leek

Of interest to note is that the FWD curvature on Nicholson Road was lower than on Warton Road (indicating a stiffer pavement on Nicholson Road); however, the cracking was typically more severe on Nicholson Road (indicating a failed pavement). Cracks on Warton Road were observed but were generally more widely spaced with no associated pumping of fines. A more severe crack on Warton Road is shown in Figure 4.11. There had been no major distress observed in the area of CRC on Warton Road at the time of preparing this report.

Figure 4.11: A typically more severe crack on Warton Road



Source: Colin Leek

The findings of the Warton Road trial indicate that:

- CRC pavements can become bound.
- The CRC pavement was generally stiff, based on the FWD curvature results.
- There may not be a relationship between severity of pavement cracking and FWD results for CRC pavements.

4.5 Discussion of Case Studies

In order to compare the performance of the case studies, the current traffic loading was sourced from the MRWA traffic map, and a 2% growth factor applied to estimate the traffic at the time of construction. The traffic loading was then assessed using the class distribution of the traffic mix and extrapolated to 2024 using the standard ESA per heavy vehicle ratios outlined in Table 11 of MRWA (2013) for Urban Freeways and Highways.

As the case studies relate to traffic induced failures, it is necessary to consider the traffic loading in terms of ESA at the time where rehabilitation was required. Table 4.3 shows the construction year, year of effective end of life (where relevant), and the design traffic loading. This does show that CRC pavements are typically suitable for many local government situations, but for the more heavily trafficked roads, the base must be designed to account for fatigue of the CRC layer. This is particularly notable for the Gilmore Avenue trial which required remediation before the design traffic had been reached due to fatigue failure of the basecourse. The typical CRC pavement designs adopted in Section 6.5 of this report do consider fatigue of CRC basecourse at higher traffic volumes.

Table 4.3: Summary of assessed pavement life for trial sections

Road name	Construction year	End of life year	Estimated traffic loading at end of life or 2024(1)	Design traffic loading
Gilmore Ave	2003	2019	2.1×10^6 ESA	7.0×10^6 ESA
Welshpool Road	2008	N/A	1.5×10^7 ESA	2.0×10^7 ESA
Nicholson Road	2008	N/A	4.6×10^6 ESA	2.2×10^7 ESA
Warton Road	2008	N/A	2.3×10^6 ESA	Unknown

1. In highest traffic direction.

5 Planning for the use of CRC

5.1 Selecting a Project

Before selecting a project for CRC, practitioners should address the following questions:

1. *What are the policy drivers for the use of recycled materials?* These may override other considerations.
2. *Do the RtR use conditions affect the project?* CRC may not be suitable for use in areas of high groundwater or PDWSAs.
3. *Is CRC economically viable?* The economics of CRC compared to alternative options will need to be considered. The location of the CRC source and haulage costs will also need to be considered.
4. *Is CRC available in sufficient quantities for this project?* CRC is typically readily available near the Perth metropolitan area, with multiple RtR accredited suppliers. However, in regional areas CRC supply may be more limited.
5. *What is the proposed road function and structure?* Using CRC as sub-base only practically eliminates the risk of block cracking and is likely suitable for most projects. If CRC is proposed as a basecourse the practitioner should review the possible risks (refer to Section 7). These risks could be managed by applying one of the options outlined in Section 7.
6. *What is the proposed surfacing type?* There is considerable experience with using CRC below an asphalt wearing course and CRC is generally considered suitable where the final wearing course will be asphalt. However, there is limited experience with CRC used as basecourse on pavements with a sprayed seal as the final wearing surface. CRC basecourse should be restricted to pavements with an asphalt wearing surface until performance in sprayed seal pavements can be demonstrated. CRC may also not be suitable for unsealed pavements due to the risk of leaching.
7. *What CRC specification will be used?* Various CRC specifications are available in WA. For LG projects it is recommended that the IPWEA/WALGA Specification for the Supply of Recycled Road Base (IPWEA/WALGA 2016) be adopted. However, it is likely that CRC specifications produced by MRWA and PTA will also be suitable for most projects.

5.2 Selecting a Pavement Profile

Once practitioners have assessed CRC to be suitable for their project, an appropriate pavement profile should be selected. Pavement profiles are included in the Practitioners Guideline, and summarised in Section 6.5 of this report.

When selecting a pavement profile for CRC the following factors must be considered:

1. *What pavement layers will CRC be used in?* I.e. whether CRC will be used as the sub-base only, or as both sub-base and basecourse. Where CRC is used in the sub-base only, it may be used as a direct substitute for typical pavement materials. Where CRC is used as basecourse it must be used as sub-base, otherwise early fatigue failure may occur (refer Section 7.4.2) and constructed to ensure a good bond between the CRC pavement layers is achieved (Refer Section 8.4).
2. *What is the design traffic?* This will affect the pavement thickness. Design traffic is discussed further in Section 6.3.
3. *What are the subgrade conditions?* This will affect the pavement thickness. Subgrade improvement or a layer of select fill may be required in areas of low subgrade CBR.

Once the above requirements are known, the appropriate pavement profile may be selected. The profiles in Section 6.5 may be adopted, or alternatively practitioners may elect to conduct their own designs.

If there is any uncertainty regarding which pavement layers should incorporate CRC, it is noted that in most instances the use of CRC as a sub-base layer is a very low risk option.

5.3 Procurement

5.3.1 Contractual Requirements

LGs will need to consider a number of factors when procuring CRC from a suppler. Contractual requirements for CRC supply should consider the following items (either within the contract or within a separate document such as a specification that is referenced by the contract):

- The requirement for the supplier to maintain an RtR accreditation for the duration of the contract.
- Appropriate record keeping demonstrating quality control of CRC materials including:
  - Source site of materials being purchased.
  - Characterisation of materials.
  - Records of sampling and testing results for materials purchased that can be traced to a NATA accredited laboratory.
  - Batch/stockpile number that corresponds to the above records.
- The engineering specification the material needs to be produced to.
- Testing requirements, including minimum testing frequencies. Testing to assess contamination and engineering properties will be required. RtR accredited suppliers will conduct their own contamination testing of CRC in accordance with the RtR Specification (Waste Authority WA, 2021) requirements; however, testing of engineering properties in accordance with the relevant specification (such as IPWEA/WALGA 2016) is also required.
- Auditing.
- Chain of Responsibility requirements. These requirements cover parties involved in the transportation of goods (includes consignors/receivers), and LGs should be aware of their requirements under the relevant legislation to ensure compliance and safety requirements are achieved.

The above list is not exhaustive and assumes that other typical contractual requirements would be included as standard.

5.3.2 Specification

In the absence of bespoke engineering specifications for CRC, the *IPWEA/WALGA Specification for the Supply of Recycled Road Base* (IPWEA/WALGA, 2016) should be used. The CRC pavement designs presented in this report assume that material complying with IPWEA/WALGA (2016) will be used.

As an option, MRWA Specification 501, Pavements, may also be used for specification of CRC sub-base (MRWA, 2023).

Recommended Constituent Materials

Where CRC is being sourced and used on projects in accordance with established specifications such as IPWEA/WALGA (2016) and MRWA (2023), the constituent material limits applicable to the relevant specification should be used.

However, as outlined in this report, blending of CRC with unmodified granular materials may help to control the UCS and therefore reduce the risk of block cracking. Where blending with unmodified materials occurs, practitioners will need to develop alternative specification requirements for the blended material for assessment of conformance, such as particle size distribution limits. These specifications will need to account for the properties of the materials being used and would likely vary for different material sources.

A summary of the constituent materials limits in the IPWEA/WALGA (2016) and MRWA (2023), plus suggested limits for blended CRC, is provided in Table 5.1.

Table 5.1: CRC constituent materials limits (limits expressed by weight)

Material	IPWEA/WALGA (Class 1)(1)	IPWEA/WALGA (Class 2)(1)	MRWA 501(2)	Blended CRC (suggested limits)
Crushed recycled concrete	<95%	<95% (basecourse) <100% (sub-base)	N/A	>50%
Recycled asphalt pavement	<10%	<15%	<15%	<10%
High density materials (brick and tile)	<10%	<15%	<15%	<20%
High density aggregates from roads etc.	<25%	<100%	N/A	<50% (3)
Low density materials (plastic, plaster, etc.)	<1%	<1.5%	<1.5%	<1.0%
Organic matter	<0.5%	<0.5% (basecourse) <1.0% (sub-base)	<1.0%	<0.5%
Unacceptable high density materials (inert materials, glass and ceramics)	<2%	<3%	<3.0%	<2.0%
Bound asbestos	As per DWER Guideline *Managing asbestos at construction and demolition waste recycling facilities* (latest version)		<0.01%	As per RtR Specification
Fibrous asbestos and asbestos fines			<0.001%	
Hazardous materials	N/A	N/A	As per RtR Specification	

1. Class 1 and Class 2 materials as defined in IPWEA/WALGA (2016). Class 1 typically basecourse, Class 2 typically sub-base.
2. MRWA (2023)
3. Source material must comply with relevant specification for basecourse or sub-base as per the intended blended material use.

5.3.3 CRC Supply

Background on CRC supply and the RtR Specification requirements is provided in Section 2 and Section 3. Preference should be given to RtR accredited suppliers when sourcing CRC as they will have undertaken the required testing to appropriately manage the risk of contamination with asbestos or metals. Sourcing CRC from suppliers that are not accredited under the RtR program increases the likelihood that contaminants will be present in the material. A list of RtR accredited suppliers is available on the Waste Authority of WA's website[1].

For LG projects it is recommended that CRC comply with the requirements of the IPWEA/WALGA Specification for the Supply of Recycled Road Base (IPWEA/WALGA 2016). This specification has been developed considering the requirements of typical LG projects and is likely to be more suitable for LG pavement construction than other CRC specifications. It is recommended this specification be referred to when specifying CRC. However, it is noted that alternative specifications may be suitable depending on the project.

Where project specifications are being developed the minimum recommended testing for physical properties of CRC is outlined in Table 5.2.

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[1] https://www.wasteauthority.wa.gov.au/programs/view/roads-to-reuse

Table 5.2: Minimum recommended testing for CRC source material

Test	Test Method	Comments
Contaminants	Various	Typically metals and asbestos. As per RtR Specification requirements. Sourcing material from a RtR accredited supplier will ensure that this testing has been undertaken and the RtR Specification requirements achieved.
Foreign material	WA 144.1	Required to ensure the CRC material does not contain deleterious materials that may affect performance. Foreign materials are discussed in Section 2.2. Suggested limits for CRC blends are provided in Table 5.1.
Particle size distribution	WA 115.1	Required to ensures the CRC will form a dense matrix following compaction and a tight surface that will be suitable for sweeping and resistant to damage before the wearing course or subsequent layer can be applied. Section 2.3.3 discusses particle size distribution.
Linear shrinkage	WA 123.1	Ensures that the portion of the product passing a 0.425 mm sieve does not undergo significant volume change with changes in moisture content. Linear shrinkage is discussed further in Section 2.3.4.
Unconfined compressive strength	WA 143.1	Required to assess the risk of shrinkage cracking due to self-cementation of the CRC. As discussed in Section 2.3.6 of this report, longer curing times for UCS testing may be required to provide an improved assessment of shrinkage cracking risk.
Los Angeles abrasion	WA 220.1	Assesses the propensity of the material to break down during handling and compaction. Material with a high LA abrasion may break down excessively which would affect its other properties such as particle size distribution and soaked CBR. Alternatively, the Micro Deval test could be considered as outlined in Section 2.3.7 (if available to the LG).
California bearing ratio	WA 141.1	Assesses the stiffness of the material once compacted. Required to ensure the material will have sufficient stiffness for use in pavements. A minimum soaked CBR of 100% should be achievable for CRC as outlined in Section 2.3.8.
Optional testing		
Resilient modulus	AGPT/T053	Considered beneficial for new suppliers or CRC sources to ensure the CRC will achieve sufficient stiffness within the pavement. Can be omitted once consistency of supply has been demonstrated. Modulus is discussed in Section 2.3.5.

5.3.4 Variability

CRC is a variable material with properties largely determined by the CRC source (structural concrete, kerbs/footpaths etc.) and the processing (crushing, screening, blending) undertaken. To maintain consistency within individual projects it is recommended that practitioners utilise CRC that has relatively homogeneous properties from a single source for each project. This would need to be discussed with the CRC supplier to ensure that sufficient quantity of material is available from the CRC source. If the CRC supply needs to be split on larger projects, the same source should be applied to each constructed lot.

5.3.5 Local Production of CRC

Some practitioners, particularly in regional areas, have indicated that they produce their own CRC from C&D material by undertaking crushing programs. Where this occurs, it is suggested that the CRC be crushed to comply with the requirements of an established specification to optimise performance of the material. However, specification requirements may need to be adjusted in some cases based on the capability of the crushing plant. For example, the particle size distribution may need to be adjusted based on the available screen aperture sizes. Where the processing cannot comply with typical specification requirements, consideration should be given to using the material deeper in the pavement profile where stresses are lower.

5.4 Areas Where use of CRC may Increase Asset Risk

LGs may want to reconsider the use of CRC in certain areas as it may introduce other risks. A summary of potential higher-risk areas that may warrant further assessment regarding the suitability of CRC is provided below. CRC may be suitable for use in these areas; however, they require closer scrutiny.

- *Pavements subject to high axle loads* (above the legal load limit): CRC pavements are assumed to behave as bound pavements in the long term. Bound pavements are sensitive to the magnitude of axle loads, and increases in axle load may significantly reduce the fatigue life of the CRC pavement if CRC is used in the basecourse layer. Pavements at risk of high axle loads or overloading, such as within industrial areas, may need to be designed for the expected overloading.
  CRC is considered suitable for use as sub-base in these areas.
- *Asphalt-surfaced paths*: If aluminium, gypsum or other potentially expansive materials are present in the CRC near the surface they may expand and cause blistering of the surface. This may present a hazard for pedestrians and cyclists. Blistering is unlikely to create a significant issue for vehicles but may increase roughness.
  Shrinkage cracking is expected to occur within the CRC as it recements. This will likely reflect through the wearing surface and present as block cracking. Generally, this would be an aesthetic issue only for most pavements however can create roughness for cyclists on shared paths.
- *Pavements where aesthetics are important*: Shrinkage cracking may occur if CRC is used as basecourse as it recements. This will likely reflect through the wearing surface and present as block cracking.
  It is noted that crack sealing may further affect aesthetics if the sealant used has a different colour or texture to the surface.
- *Unsealed pavements*: Under the RtR Specification, road base containing concrete and with a pH greater than 9 may only be used below a bituminous seal or asphalt. This is to reduce risks associated with leaching of high-pH material.
  The RtR Specification does allow material with a pH below 9 to be used where not surfaced with a bituminous seal or asphalt.
- *Areas near groundwater or public drinking water source areas*: The RtR Specification restricts the use of CRC in areas where groundwater or public drinking water source areas may be affected. The current version of the RtR Specification should be referred to for further up to date information.

6 Design of CRC Pavements

6.1 Design Considerations

In this report, the potential behaviour of CRC as both a bound or unbound material has been considered for the purpose of pavement design. This is to account for the expected variability of the material across different projects, in particular the residual cement present in the CRC. Experience with CRC trial pavements (for example, Section 4.1) indicates that fatigue of CRC is unlikely at lower traffic volumes. Fatigue of CRC basecourse has not been considered for traffic volumes of 3×10^5 ESAs or below.

The design of CRC pavements will be dependent on the properties of the material. CRC, as the name implies, has a proportion of crushed concrete within the mix, but other hard rock material will be present, typically in the form of fired clay products, sands and gravels. Gravel size particles can include old pavement materials, including crushed rock.

The crushed concrete component will contain cement, but there may be other pozzolanic materials contained in the mix from other sources. Pozzolans are a broad class of siliceous and aluminous materials which, in themselves, possess little or no cementitious value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties; the same compounds that occur in Ordinary Portland Cement (Mehta 1987).

The current knowledge gaps in the behaviour of CRC in pavements means that the proportion of non-pozzolanic materials required to prevent CRC from becoming a bound pavement is not well understood. However, it is recognised that at some mix proportion of crushed concrete, other pozzolans and other non-pozzolans, the CRC will transition from becoming bound, to remaining unbound.

It must be noted that the designs only consider subgrade strength. Other factors, such as shrink-swell movements or poor drainage conditions, may require an increase to the pavement thickness or the inclusion of a select subgrade layer. The requirement for these layers will be dependent on site-specific conditions and is beyond the scope of this report.

6.2 Design Method

Pavement designs incorporating CRC have been conducted in accordance with the requirements of Austroads (2012), which uses an ESA approach to assessing design traffic. It is noted that this document was updated in 2017 to incorporate a HVAG approach to design traffic assessment; however, the ESA approach in the 2012 version of the guide was selected for two reasons:

1. The HVAG approach requires information on the load distribution of each type of heavy vehicle. There is limited information with the required level of detail available for local government roads, and the loading might vary considerably between different roads.
2. The ESA approach has been used widely for many years and is still used by MRWA at the time of writing. There is significant evidence that assessment of design traffic using ESAs is a suitable approach to pavement design.

The pavement designs are based on assumed material properties as outlined in Section 6.4.

To account for the potential bound or unbound behaviour of CRC, which may vary between projects, both the empirical and mechanistic methods in Austroads (2012) have been used. Mechanistic design of pavements has been conducted using an ESA approach and the program CIRCLY 6.0. Bound behaviour has only been considered where CRC is used in the basecourse layer, and only for traffic volumes above 3×10^5 ESAs.

It must be noted that fatigue of any asphalt layers has not been considered in the designs presented in this report and the accompanying guideline. However, as CRC basecourse is generally very stiff and traffic volumes on LG roads are typically low to moderate, asphalt fatigue life is unlikely to be the factor governing design life.

6.3 Design Traffic Volumes

Design traffic volumes ranging from 1 × 10^4 ESAs to 1 × 10^7 ESAs have been adopted for the pavement designs presented in this report. The designs assume a 40-year pavement design life.

Practitioners should consider expected construction vehicle traffic when selecting a CRC pavement design. For example, residential subdivisions typically have high volumes of truck movements within the first few years.

CRC may be suitable for pavements with design traffic volumes above 1 × 10^7 ESAs, particularly as sub-base; however, it is recommended that project-specific pavement designs be conducted.

Practitioners are reminded that the importance of uniform and conforming pavement construction materials increases with design traffic loading. CRC (or any other pavement material) should only be specified for high traffic conditions where there is confidence in the quality of the material source.

Practitioners should make their own assessment of design traffic to facilitate selection of an appropriate design profile.

6.4 Assumed Material Properties

In the design of bound CRC pavements, material properties are a critical input. It is usually the case that the failure mode is fatigue of the bound (CRC) layer, rather than the vertical strain on the subgrade, which is the critical design determination in unbound pavements.

As outlined in Section 8.1, where CRC is used in basecourse construction it is prudent that the CRC pavement layers are well bonded and behave as a single layer to ensure the design pavement life is reached.

The material properties used to conduct the pavement designs presented in Section 6.5 are summarised in Table 6.1. The properties assumed for CRC are considered to be relatively conservative; however, as there is limited publicly available information on the properties of locally sourced CRC materials, it was considered prudent to adopt a conservative approach.

Table 6.1: Design parameters used for mechanistic CRC pavement design

Pavement Layer	Modulus of Elasticity (MPa)	Poisson's Ratio	Degree of Anisotropy
CRC as Sub-base, CRC as Basecourse and Sub-base for 3 × 10^6 ESAs and below (unbound design parameters)			
Asphalt	2,200	0.40	1
Granular Basecourse (unbound)	350	0.35	2
CRC Sub-base	250	0.35	2
CRC as Basecourse and Sub-base for >3 × 10^6 ESAs (bound design parameters)			
Asphalt	2,200	0.40	1
Combined CRC Basecourse and Sub-base(1)	2,000(2)	0.20	1
Subgrade			
CBR 8%, 12% (sandy subgrade)	80 / 120	0.35	2
CBR 5% (clayey subgrade)	50	0.45	2

1. CRC basecourse and sub-base must be well bonded to form a homogenous layer. Refer Sections 7.4.2 and 8.4.
2. Flexural modulus.

Practitioners conducting their own pavement designs may use the design parameters presented in Table 6.1 as a starting point for pavement design.

6.5 Design Sections

The CRC pavement designs presented in this report assume that the IPWEA/WALGA Specification for the Supply of Recycled Road Base (IPWEA/WALGA, 2016) will be used for specification of CRC.

CIRCLY design sheets for options where CRC is used as basecourse (bound pavement design for traffic volumes above 3 × 10^6 ESAs) are provided in Appendix A.

6.5.1 CRC as Sub-base

Direct Replacement

Where CRC is used in the sub-base only and overlain by a granular basecourse layer, it is acceptable to use it as a direct replacement for other sub-base materials. LGs may adopt their typical pavement profiles and replace their typical sub-base materials with CRC. No further design is considered necessary in this instance.

Alternatively, the designs presented below may be used.

Pavement Designs

CRC pavement design profiles for CRC used as sub-base only are provided in Table 6.2. Pavement designs have been developed assuming an unbound pavement structure.

Crack mitigation is optional but should be considered based on the risk tolerance for block cracking for each project.

Table 6.2: CRC Pavement design profiles – CRC as Sub-base

Pavement Layer	Thickness (mm)
Wearing Course	Type and thickness to be selected by LG
Crack Mitigation (optional)	Refer Section 6.6
Unbound Granular Basecourse	Refer Table 6.3
CRC Sub-base	Refer Table 6.3

The minimum unbound granular basecourse and CRC sub-base thickness requirements are summarised in Table 6.3.

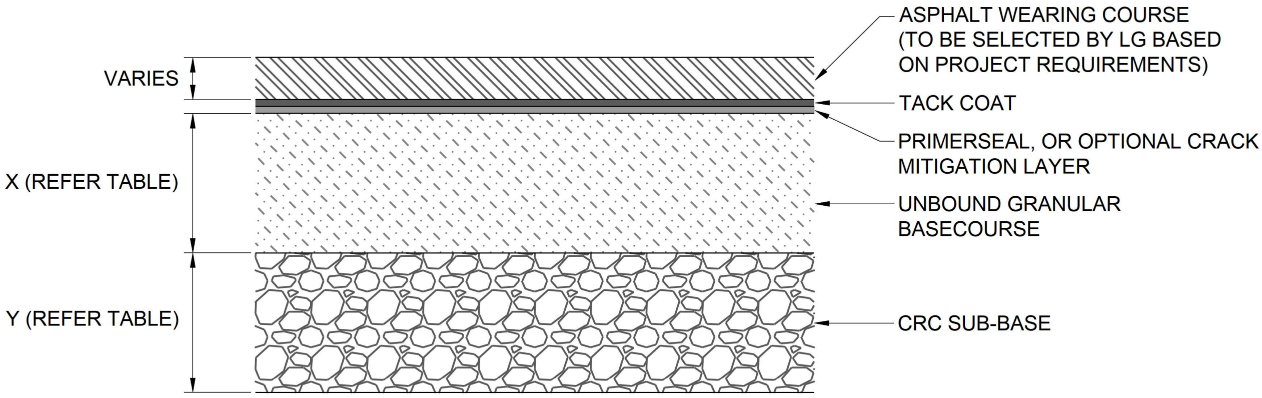
Table 6.3: Minimum unbound granular basecourse and CRC sub-base thicknesses

Subgrade Design CBR (%)	Design Traffic (ESAs) and Minimum Basecourse / Sub-base Thickness (mm)(1)						
	1 × 10^4	3 × 10^4	1 × 10^5	3 × 10^5	1 × 10^6	3 × 10^6	1 × 10^7
5	100 / 100	100 / 140	100 / 195	115 / 225	135 / 260	150 / 290	170 / 325
8	100 / 75	100 / 85	100 / 125	115 / 145	135 / 165	150 / 185	170 / 205
12	75 / 75	75 / 75	100 / 75	115 / 85	135 / 95	150 / 110	170 / 120

1. Values presented as "Basecourse / Sub-base". I.e. 100 / 75 = 100 mm basecourse and 75 mm CRC sub-base

A design profile for CRC as sub-base is included in Figure 6.1.

Figure 6.1: Design profile – CRC as sub-base



SUBGRADE DESIGN CBR	TRAFFIC VOLUME (ESAs) / X/Y (mm)						
	1 x 10^4	3 x 10^4	1 x 10^5	3 x 10^5	1 x 10^6	3 x 10^6	1 x 10^7
5%	100 / 100	100 / 140	100 / 195	115 / 225	135 / 260	150 / 290	170 / 325
8%	100 / 75	100 / 85	100 / 125	115 / 145	135 / 165	150 / 185	170 / 205
12%	75 / 75	75 / 75	100 / 75	115 / 85	135 / 95	150 / 110	170 / 120

Note: ESAs - Equivalent standard axles

CRC AS SUB-BASE

Source: WSP

6.5.2 CRC as Basecourse and Sub-base

Where CRC is used in both the basecourse and sub-base layers, pavement designs have been developed considering both unbound and bound behaviour of CRC. It must be noted that for this option there are no separate basecourse and sub-base layers; rather, the pavement is one homogenous layer of CRC that may be constructed in multiple layers depending on the pavement thickness. Bonding between each constructed layer is critical to optimising the life of the pavement (refer Section 8.4).

Fatigue of the CRC layer has not been considered for traffic volumes of 3 × 10^5 ESAs or below. In the author's experience, fatigue of CRC causing a significant reduction in pavement life is unlikely to occur at these relatively low traffic volumes. However, practitioners should note that thin CRC pavement layers may be more susceptible to fatigue if excessive traffic loading occurs.

CRC pavement design profiles for CRC used as basecourse and sub-base are provided in Table 6.4.

Table 6.4: CRC Pavement design profiles – CRC as Basecourse and Sub-base

Pavement Layer	Thickness (mm)
Asphalt Wearing Course	Type and thickness to be selected by LG
Crack Mitigation (recommended)	Refer Section 6.6
CRC Basecourse and Sub-base	Refer Table 6.5

The minimum combined CRC basecourse and sub-base thickness requirements are summarised in Table 6.5. Individual CRC layers should typically be placed between 100 mm and 250 mm compacted thickness and be well bonded as outlined in Section 8.4.

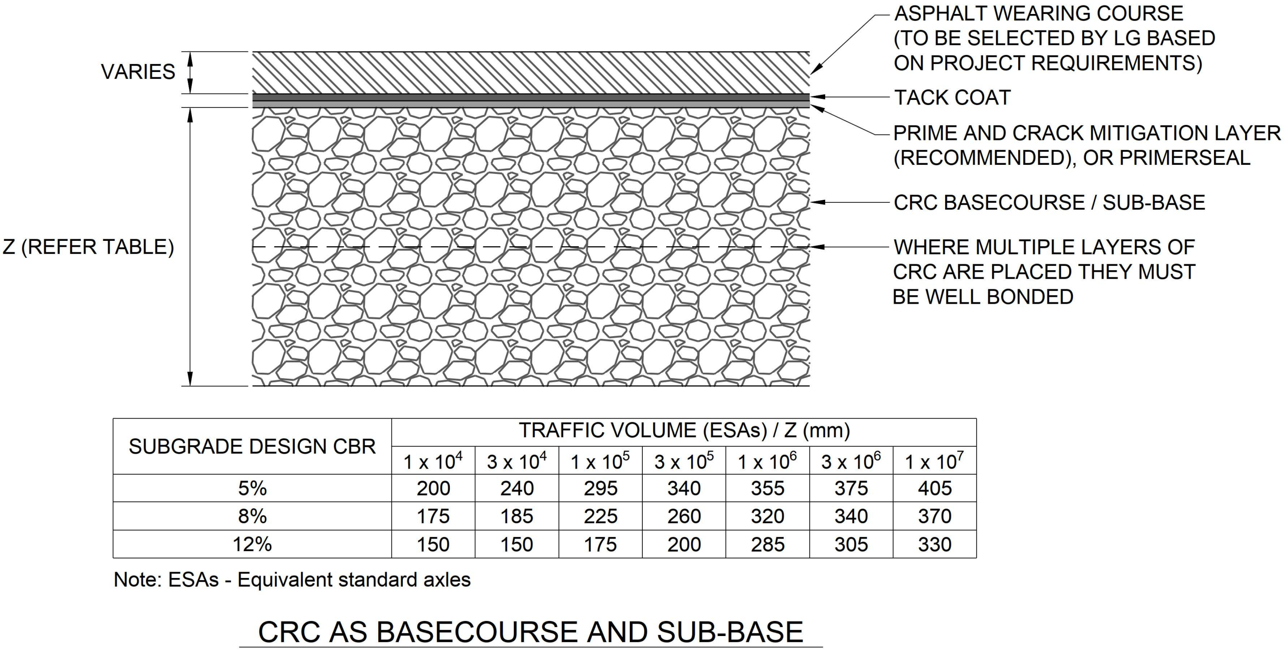
Table 6.5: Minimum CRC sub-base and basecourse combined layer thickness requirements

Subgrade Design CBR (%)	Design Traffic (ESAs) and Minimum Total CRC Thickness (mm)[1]						
	1×10^4	3×10^4	1×10^5	3×10^5	1×10^6	3×10^6	1×10^7
5	200	240	295	340	355	375	405
8	175	185	225	260	320	340	370
12	150	150	175	200	285	305	330

1. Fatigue of CRC layer not considered for design traffic volumes of 3×10^5 ESAs or less.

A design profile for CRC as basecourse and sub-base is included in Figure 6.1. Where the required level of compaction can be achieved for the full thickness of the pavement, construction of the basecourse and sub-base as one combined layer may be considered, as this eliminates the potential for a poor bond to occur at the sub-base/basecourse interface.

Figure 6.2: Design profile – CRC as basecourse and sub-base



SUBGRADE DESIGN CBR	TRAFFIC VOLUME (ESAs) / Z (mm)						
	1×10^4	3×10^4	1×10^5	3×10^5	1×10^6	3×10^6	1×10^7
5%	200	240	295	340	355	375	405
8%	175	185	225	260	320	340	370
12%	150	150	175	200	285	305	330

Note: ESAs - Equivalent standard axles

Source: WSP

6.5.3 IPWEA Local Government Guidelines for Subdivisional Development Pavement Profiles

IPWEA (2016) provides various pavement profiles for urban pavements. While the CRC designs presented in Sections 6.5.1 and 6.5.2 are generally recommended, where LGs would typically adopt an IPWEA (2016) pavement profile, CRC may be used as direct replacement for the sub-base layers.

6.6 Crack Mitigation

Crack mitigation is typically not required where CRC is used as a sub-base only, as the presence of the overlying unbound granular basecourse provides some resistance to the reflection of block cracking in the CRC layer through the wearing course. However, practitioners can elect to include additional crack mitigation measures depending on the risk tolerance of their specific project.

The intent of crack mitigation is to reduce the risk and severity of cracks occurring in the CRC pavement from affecting the wearing course. It may comprise an additional pavement layer included specifically for this purpose (typically a type of sprayed seal such as a SAMI) or adjustments to the properties of the asphalt wearing course.

Where the reflection of block cracks in the CRC through the wearing course needs to be managed, several options may be considered. The benefits and risks associated with each option are discussed further in Section 7.1. It should be noted that inclusion of the crack mitigation options does not guarantee cracking will not occur, rather it will delay the onset and severity of cracking which does occur in the CRC layer from reflecting through the wearing course.

The crack mitigation options provided broadly fall into three categories:

1. A thickness of unbound granular basecourse above the CRC layer, where CRC is used as sub-base.
2. A separate crack mitigation layer below the wearing course (essentially a type of seal).
3. Modification of the asphalt wearing course, such as with a polymer or fibre reinforcement.

Reflection cracking may be more tolerable in some areas, and this should be considered when assessing the requirement for additional crack mitigation. For example, car parks and roads within commercial areas may not have the same aesthetic requirements as roads within residential areas.

6.6.1 Crack Mitigation Layer Options

Options for the crack mitigation layer are provided in Table 6.6. For most situations, a SAMI should be suitable.

Table 6.6: Crack mitigation layer options

Option	Requirements
Option 1 – SAMI **(recommended in most instances)**	• Prime. • S20E or S45R bitumen at 1.6 L/m^2 (residual bitumen at 15°C). • 10 mm sealing aggregate at 140-160 m^2/m^3. • Tack coat and asphalt wearing course.
Option 2 – GRS(1)	• Prime. • C170 bitumen bond coat at 0.8 L/m^2 (residual bitumen at 15°C). • Minimum 130 g/m^2 polyester non-woven geotextile fabric. • C170 bitumen with or without 5% crumb rubber at 1.1 L/m^2. • 10 mm sealing aggregate at 160-180 m^2/m^3. • C170 bitumen with or without 5% crumb rubber at 0.6 L/m^2. • 5 mm sealing aggregate at 180-220 m^2/m^3. • Tack coat and asphalt wearing course.
Option 3 – Asphalt Geogrid(2)	• Prime. • C170 bitumen bond coat at 0.4-0.8 L/m^2. • Asphalt geogrid. • Asphalt wearing course.

1. Assumed geotextile bitumen absorption of 1.0 L/m^2. All application rates are indicative only. A final design must be conducted on a case-by-case basis to account for the properties of the geotextile, binder and aggregate used.
2. The requirements for this layer and the bond coat requirements must be confirmed with the asphalt geogrid supplier and may need to be adjusted on a project basis. Asphalt geogrid suppliers have strict requirements for installation of their products which must be followed.

6.6.2 Other Crack Mitigation Options

Other options for crack mitigation that do not incorporate a separate crack mitigation layer are summarised in Table 6.7. The authors note that Option 4, fibre reinforced asphalt, has been used successfully on multiple LG projects with minimal effect on asphalt cost.

Table 6.7: Other crack mitigation options

Option	Requirements
Option 4 – Fibre reinforced asphalt	• Virgin Polyolefins and/or Virgin Aramid fibres. • Fibre length two times aggregate size. • A dosing rate of about 500 g/tonne may be appropriate.
Option 5 – Bottom layer SMA	• Inclusion of a layer of SMA with polymer modified binder and high bitumen content below the wearing course.
Option 6 – Alternative asphalt types	• Polymer modification of the asphalt wearing course. A15E polymer modified binder may be suitable in most instances, or • SMA with polymer modified binder, or • Fine gap graded asphalt with polymer modified binder.

7 Mitigation of Risks

7.1 General CRC Risk Profile

While CRC produced and constructed to an appropriate specification is a suitable material for pavement construction, it has a different risk profile to quarried materials due to it being a recycled material that contains residual cement. The key risks associated with CRC that differ from other materials are:

- Block cracking.
- Surface blisters.
- Fatigue cracking.

All of these risks can be addressed by adopting CRC in the sub-base layer of the pavement and overlying it with an unbound granular basecourse, as per the designs presented in Section 6.5.1.

Where CRC is used as basecourse the likelihood of the above issues occurring increases. They can all be managed by only adopting CRC basecourse in appropriate circumstances and by following recognised design procedures.

7.2 Block (Shrinkage) Cracking

7.2.1 Overview

CRC which contains sufficient residual cement will form essentially a low to moderate stiffness concrete pavement over time, and as with concrete pavements, cracks should be expected due to drying shrinkage. However, unlike concrete pavements, deliberate cracking of CRC pavements is not undertaken (*e.g.* there are no sawn joints), and cracks will occur at random locations. This is known as block cracking or shrinkage cracking.

The risk of block cracking occurring in the CRC reflecting through the wearing course increases as the cover above the CRC reduces. Block cracking reflecting through the wearing course is unlikely where CRC is used as a sub-base layer only.

Block cracking in CRC pavements does not indicate structural failure, and block cracking has occurred in pavements constructed from unmodified natural gravels or quarried materials, typically where the plasticity index or linear shrinkage are moderately high, or cementation occurs naturally over time. Block cracking is an aesthetic issue only provided that the pavement is otherwise performing as per the design intent and moisture ingress is not affecting performance.

Figure 7.1 shows an example of a block cracking pattern on a low traffic residential street.

Figure 7.1: Typical block cracking on a low traffic residential street

Source: Simon Hull

The risk of block cracking generally correlates with the UCS of the material, with materials with higher UCS typically having increased risk and severity of block cracking. Controlling the UCS of the material may help manage the risk of block cracking. Where this is not feasible, surface treatment to maintain waterproofing and reduce the occurrence block cracks reflecting through the wearing course can be adopted to prevent loss of fines from the surface and prevent water ingress (refer Section 6.6). It is noted that UCS testing at the relatively long curing periods expected to be required for most CRC materials (at least 28 days) may be impractical for production control of CRC.

7.2.2 Control of Block Cracking through Overlying Unbound Material

The preferred and most cost-effective method of mitigating block cracking is to use CRC in the sub-base layer only and provide an unbound basecourse. Block cracking which occurs in the CRC layer should be “absorbed” through the unbound granular layer and is unlikely to propagate through the wearing course.

Block cracking may occur after some time, but this can be addressed during normal resurfacing treatments, possibly incorporating a crack mitigation layer at the time resurfacing is conducted. This has the benefit that crack mitigation layers are only applied to pavements where they are necessary.

The CRC pavement designs in Section 6.5.1 include an unbound basecourse layer to manage block cracking.

7.2.3 Control of Block Cracking through Crack Mitigation Layers

The use of crack mitigation layers, particularly SAMIs, has been demonstrated to resist cracking of underlying layers (Austroads, 2018). If the CRC pavement is expected to block crack and control of cracking at surface level is required, there are several options to help delay the onset of cracking becoming visible at the surface and reduce its severity. However, these options are unlikely to prevent block cracking from reflecting through the wearing course in the long term. The following options could be considered:

- SAMI – a relatively heavy application of polymer or rubber modified bitumen below the asphalt wearing course.
- GRS – a layer of geotextile overlain by a sprayed seal. Typically uses unmodified or lightly modified bitumen. A GRS must not be used in higher-stress areas such as intersections or braking zones as shear failure can occur at the GRS layer from traffic forces.
- Asphalt geogrid reinforcement – a layer of geogrid specifically developed for use below an asphalt wearing course.

The above options all provide an additional layer below the wearing course intended to bridge across cracks that occur in the CRC pavement and reduce the risk of cracks reflecting through the overlying layer. They do not stop block cracking from occurring within the CRC layer.

A summary of the identified risks and benefits associated with the above options is presented in Table 7.1.

Table 7.1: Benefits and risks

Option	Benefits	Risks
SAMI	Likely to be lower cost than other options. Relatively quick to construct (a SAMI is essentially a heavy single/single seal). Can be used on roundabouts and tight curves.	Has negligible tensile strength. Likely has shortest period before block cracking starts to appear. Cannot apply heavily modified bitumen directly to CRC or it may not adhere. A prime coat is required.
GRS	Has significant tensile strength. Expected to prevent reflection of block cracking for significant time.	Expensive to construct. Cannot be used on roundabouts, or tight curves, intersections or braking areas due to potential slippage under shear loading from vehicles. Requires significant quantity of bitumen.
Geogrid	Has significant tensile strength. Expected to prevent reflection of block cracking for significant time. Can be placed by hand for small sections. Can be used on roundabouts and tight curves.	Limited construction experience in Western Australia. Geogrid performance is sensitive to construction quality and further advice from geogrid suppliers will be required. Currently suppliers may require an underlying asphalt layer and minimum 50 mm thickness of overlying asphalt(1).

1. Suppliers may allow relaxation of these requirements depending on the project. Practitioners are encouraged to discuss requirements with geogrid suppliers directly to confirm requirements for individual projects.

7.2.4 Control of Block Cracking through Asphalt Surfacing

While the surfacing type may have some effect on the severity of block cracking which reflects through the surfacing, with the exception if including fibres within the asphalt, it may be less effective than the options provided in Section 7.2.2. The use of polymer modified bitumen within the asphalt surfacing may provide some resistance to reflective block cracking but it should not be relied upon.

Asphalt types such as SMA and fine gap graded asphalt with a polymer modified bitumen may provide some resistance to reflective block cracking. Materials such as bottom layer SMA (typically a thin layer of relatively fine SMA with polymer modified binder) could also be used and are likely to provide some resistance to block cracking.

The author’s experience has shown that the addition of aramid or polyolefin asphalt reinforcing fibres can resist reflective cracking. Where reinforcing fibres are used appropriate controls would need to be implemented to ensure a suitable, homogeneous asphalt mix is produced.

7.2.5 Control of Block Cracking through Unconfined Compressive Strength

As outlined above, the occurrence of block cracking is generally related to the UCS. Therefore, controlling the UCS should help to reduce the occurrence of block cracking. Cocks *et al* (2017) indicates that blending

CRC with up to 50% crushed brick and tile or ferricrete did not appear to affect the UCS of CRC blends significantly.

Blending of CRC to manage block cracking by reducing the UCS of the material should be treated as a trial until it has been demonstrated to be effective.

It is noted that blending relatively high proportions of granular materials with CRC may not comply with the requirements of more common CRC specifications, such as IPWEA/WALGA (2016) Class 1 material and MRWA (2023). Bespoke project specifications would need to be developed for the blended product to assess conformance. Advice on suggested specification limits for blended material is provided in Section 5.3.2.

It is also noted that IPWEA/WALGA (2016) does allow for “blends” of material that comply with the Class 2 requirements as outlined in the specification. For example, blends containing 50% CRC:50% high density aggregates or 30% CRC:70% high density aggregates both comply with the requirements for a Class 2 material in Table 2 of IPWEA/WALGA (2016).

Alternatively, moisture conditioning the CRC in stockpiles, with associated regular turning over of material, could help interrupt formation of cementitious bonds before the CRC is used in the pavement. The bonds which form following moisture conditioning would be broken during subsequent handling and compaction of the material. Due to the slow rate of strength gain of CRC this may be required for some time to have a significant effect on the UCS (possibly longer than 28 days).

7.2.6 When to Control Block Cracking

The CRC pavement designs presented in this report incorporate optional treatments for control of block cracking. It is up to each LG to assess the risks associated with cracking on a project basis. The following is provided to help guide LGs in assessing the requirement to address the risk of block cracking:

- CRC used as basecourse – higher risk of cracking. Crack mitigation treatment recommended. Cracking may occur, but treatment will help reduce extent and severity of cracking.
- CRC used as sub-base, less than 150 mm granular material cover above CRC – low risk of cracking, although if cracking occurs, possibly not until the medium to long term. Crack mitigation treatment optional, but recommended if basecourse comprises moisture-sensitive material such as CRB that may pothole if moisture ingress occurs.
- CRC used as sub-base, greater than 150 mm of granular material cover above CRC – low risk of cracking, possibly not until the long term. Crack mitigation treatment unlikely to provide significant benefit in the short term but should be considered if the consequences associated with cracking are high.

7.2.7 Treatment of Block Cracking

Block cracking on its own is not an indication of structural pavement failure. However, block cracks can allow surface water to infiltrate the pavement and accelerate the rate of deterioration (commencing as pumping of fines from the basecourse). This can lead to erosion within the pavement and loss of surface shape. To optimise the pavement life where block cracking has occurred, a program of crack sealing is recommended. A typical polymer modified bituminous crack sealing product, as would be used for other crack sealing works, is recommended.

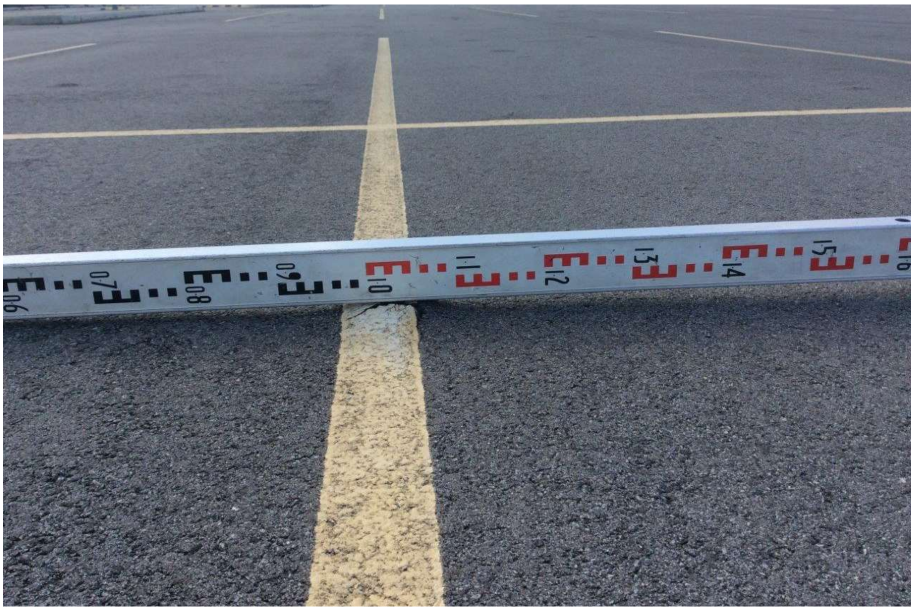
7.3 Surface Blistering/Domes

7.3.1 Overview

Some impurities present in CRC can expand, typically in the presence of moisture, which can cause localised domes/blisters on the pavement surface where they occur just below the wearing course. The typical effect of these impurities (metallic aluminium and gypsum) is outlined in Section 2.5.3.

Figure 7.1 shows an example of surface blistering.

Figure 7.2: Example of surface blistering within a public car park



Source: Colin Leek

7.3.2 Control of Surface Blistering

Controlling the risk of surface blistering can be achieved in two ways:

1. By limiting the occurrence of expansive impurities in the CRC, or
2. By ensuring that expansive impurities aren't present close to wearing surface level.

Controlling the occurrence of expansive impurities in CRC requires control of the CRC source material and processing operations to such an extent that they are present in very low proportions. It is unlikely the occurrence of such impurities can be eliminated.

Firstly, where possible the CRC source material should be controlled to ensure that potential impurities are not mixed into the CRC source stream. This requires proper handling and sorting of materials at the demolition site (or other source) and may be beyond the control of most practitioners. Sourcing CRC from a RtR accredited supplier will help ensure a high level of control over the CRC stream but does not provide assurances on the levels of metallic aluminium or gypsum present in the material.

If control of the CRC source is not practicable, some impurities such as metallic aluminium can be removed from the material. This is typically undertaken using eddy current separation which induces a magnetic field in non-ferrous materials (such as aluminium). Some CRC suppliers in the Perth metropolitan area have the facilities to remove metallic aluminium and other non-ferrous metals, and it is recommended that practitioners enquire with proposed CRC suppliers to understand their capabilities.

Alternatively, if expansive impurities are present and the occurrence of surface blistering is unacceptable then CRC should not be used in the basecourse layer.

CRC containing expansive impurities is considered suitable for use as sub-base, as the overlying basecourse layer will help to limit the amount of expansion and spread any expansion that may occur over a wider area. The proportions of impurities present will need to be limited to comply with the specification being used.

7.3.3 Treatment of Surface Blistering

Where surface blistering occurs, the affected areas would typically be relatively small and isolated, unless there is significant contamination of the CRC with impurities. Treatment would typically comprise localised removal of the affected wearing course and a portion of the CRC (to remove the impurities), and application of an asphalt patch. In most cases patching of an area about 20 cm by 20 cm would be sufficient to treat a surface blister.

7.4 Fatigue Cracking

7.4.1 Overview

Fatigue cracking of CRC pavements results from insufficient design thickness where the CRC layer is behaving as a bound pavement. The action of traffic causes the bound layer to flex, and fatigue cracking develops at the base of the bound layer under successive vehicle passes, with the cracks extending towards the top of the layer over time. The rate of development of fatigue cracking depends on:

- The thickness of the bound layer. Thinner layers will develop fatigue cracking more rapidly.
- The traffic composition. Higher traffic volumes and/or higher axle loads will accelerate the rate of fatigue cracking.
- The location of the bound layer. Bound basecourse layers are more likely to fatigue crack. Sub-base layers are unlikely to fatigue crack.
- The support below the bound layer. Lower stiffness layers underlying the bound layer will accelerate the development of fatigue cracking.

For example, consider an existing moderately trafficked pavement comprising replacement of an existing 100 mm crushed rock basecourse layer with CRC on a 200 mm thick crushed limestone sub-base. If the crushed rock basecourse is replaced with 100 mm of CRC there is a high likelihood of fatigue cracking as the CRC layer is relatively thin, traffic volumes are not low, and the CRC is being used as basecourse.

Fatigue cracking of bound pavement layers should not be confused with fatigue of the asphalt surfacing, which relates to the properties of the asphalt and level of support provided by the underlying pavement structure (whether bound or unbound). Where fatigue cracking has occurred, practitioners may need to obtain professional advice to identify the likely cracking type.

Fatigue of CRC pavements is only likely to be an issue where CRC has been used for the basecourse layer only and traffic loading is moderate to high. Fatigue cracking of CRC pavements is unlikely in areas of low traffic loading unless the CRC is used for basecourse only and the CRC layer is relatively thin.

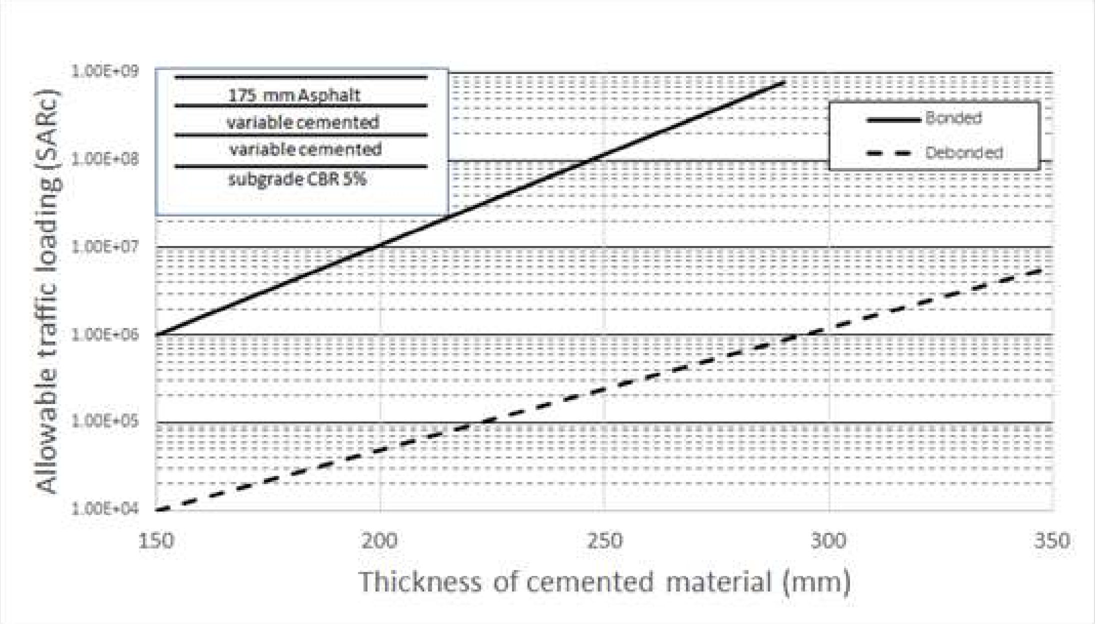
An example of fatigue cracking of a CRC pavement is shown in Figure 4.4 in Section 4.1. The fatigue cracking is evidenced by closely-spaced crocodile cracking of the surface. It must be noted that differentiating fatigue cracking that has occurred within the pavement from that which has occurred at the surface only may require further investigation.

7.4.2 Control of Fatigue Cracking

To reduce the risk fatigue cracking occurring in bound CRC pavements, proper attention to design and design inputs is required. Where CRC is used as the basecourse it must also be used as the sub-base, and the two layers must be constructed such that sufficient bond is achieved between the layers and they act as a single homogenous pavement structure.

Figure 7.3 shows the effect of a bonded (i.e. pavement acting as a homogenous layer) and unbonded (i.e. pavement acting as separate layers) interface between two bound pavement layers; in this case on a CBR of 5% and with 175 mm asphalt surfacing. For a cemented material (CRC) layer thickness of 250 mm, debonding between layers reduced the design life from 1.0 x 10^8 ESAs to 1.1 x 10^5 ESAs, almost three orders of magnitude.

Figure 7.3: Effect of debonding of pavement layers



Source: Colin Leek

To adequately control fatigue cracking of CRC pavement layers the following parameters must be considered:

1. Design traffic volume, which may need to consider relatively infrequent movements of overloaded vehicles depending on the pavement location.
2. Subgrade support. Higher stiffness subgrades should increase the fatigue life of overlying pavement layers.
3. CRC properties. It is noted that the properties of CRC may be variable and limited testing of CRC modulus has been undertaken. Where practitioners are undertaking their own bound pavement designs, and in the absence of additional information, a design flexural modulus of 2,000 MPa may be appropriate for bound CRC pavement layers.
4. Pavement construction, ensuring a good bond between the CRC layers as outlined in Section 8.4.

7.4.3 Treatment of Fatigue Cracking

The only long-term remediation treatment for a fatigue cracked CRC pavement is to reconstruct or stabilise the affected pavement layers. Resurfacing in accordance with the general requirements presented in Section 7.2.2 may be considered as a temporary treatment; however, reflection of the fatigue cracking through the resurfacing should be expected.

The reconstruction requirements for each project will be different and are beyond the scope of this report.

As an interim measure for temporary treatment only, resurfacing with a crack mitigation layer in accordance with Section 6.6.1 could be undertaken. Cracking should be expected to reoccur through the surfacing in the short to medium term. The use of asphalt reinforcing grids may provide a longer-term solution than other options such as a SAMI, as the grid will allow tensile reinforcement of the asphalt layer. The asphalt reinforcement grid must be installed in accordance with the supplier’s requirements.

8 Construction of CRC Pavements

8.1 General CRC Behaviour during Construction

In general, CRC behaves similarly to other granular pavement construction materials, such as crushed rock base, and contractors familiar with granular pavement construction are unlikely to have significant issues placing, moisture conditioning and compacting CRC. The same general requirements for other granular materials also apply to CRC, such as appropriate moisture conditioning, roller selection, and the need for dryback prior to construction of overlying layers.

8.2 Layer Thickness

Where the subgrade soaked CBR is 10% or greater, has been sufficiently compacted and therefore provides adequate support, it is expected that up to a 300 mm thickness pavement layer can be compacted in one lift, subject to appropriate roller mass/vibration, rolling patterns and moisture conditioning of the material being compacted.

As the subgrade CBR decreases, the “anvil” against which the material is compacted against reduces in stiffness and the density is more likely to reduce towards the base of the layer. In this case placement of a select subgrade layer or reduced CRC layer thickness may be required.

As traffic loading increases, it is also necessary to ensure that the upper layer provides sufficient stiffness to prevent excessive curvature that will reduce asphalt fatigue life. Compaction of the pavement in multiple layers can help ensure adequate stiffness of the upper layers.

CRC should not be placed in layers of less than 75 mm compacted thickness, although this may need to be adjusted if material with a coarser grading than provided in IPWEA/WALGA (2016) is used.

8.3 Compaction

As for other granular materials, compaction of CRC close to optimum moisture content is important to ensure the required density can be achieved. It is especially important where CRC is used as basecourse as the soil suction induced during dryback from optimum moisture content can help improve the stiffness of the pavement.

The compaction moisture content must not be reduced in an attempt to prevent rehydration of the cement and associated block cracking. This will reduce the density that can be achieved, and hence the stiffness of the pavement, and is unlikely to have significant effect on rehydration since the volume of water required for this to occur is low (about one-third of the residual cement content). For example, a moisture content of only about 0.35% is theoretically capable of hydrating the cement in a pavement containing 1% residual cement.

8.4 Interlayer Bonding

As outlined in Section 7.4.2, the fatigue performance of bound CRC pavements is sensitive to the thickness of the bound CRC layer. Where multiple layers of CRC are constructed (for example, CRC sub-base and basecourse layers), development of a strong interlayer bond is critical to optimising the life of the pavement. If a strong bond between the bound CRC layers is not achieved, the fatigue life of the basecourse will be significantly shorter than the design indicates.

To achieve a strong bond between CRC layers, the first layer should be laid and compacted as usual, but covered as soon as possible with the second layer before the first layer has dried back (provided that it is at or below 100% of optimum moisture content (modified compaction)). A light scarifying of the surface of the first layer is recommended prior to application of the overlying CRC layer. A light application of water may also assist in achieving a good bond.

By applying this method, the two CRC layers should develop a bond as the hydration process commences. The intent is that the two layers will act as if constructed as a single homogenous layer, increasing the fatigue life of the pavement.

Where possible, construction of CRC in a single layer is preferred, as it eliminates the risks associated with bonding between layers, but does require appropriate roller mass. Depending on the layer thickness, construction trials may be required to demonstrate the specified level of compaction can be achieved.

8.5 Trimming

CRC can develop significant stiffness due to the residual cement present in the material. Contractors have advised that CRC can become difficult to trim with a grader if excessive time elapses between completion of construction and trimming. Increased wear on grader blades has also been reported.

It is recommended that CRC pavements be trimmed within about 24 hours of construction of the layer. Trimming the day following construction has been reported to be a suitable approach.

8.6 Dryback

When used as a basecourse, a longer dryback period is recommended. Chemical action in the hydration process will assist in obtaining dryback, but additional time should be allowed for the shrinkage from the hydration process to develop. This will reduce the risk of later shrinkage cracking.

8.7 Surface Finish and Priming

CRC has typically produced a good finish suitable for application of a prime and selected wearing course on projects the authors have been involved in. However, CRC can create a smooth and tight finish in some instances which can affect penetration of the prime and bonding to the wearing course.

If a smooth/tight surface finish occurs it should first be vigorously swept with a rotary broom with nylon brushes to try and improve the surface texture. Brooms with steel in their bristles may be too harsh and damage the surface. Adjustments to the prime composition and rate may also be required to promote good penetration into the CRC. A reduction in bitumen content of the prime (*i.e.* increase in cutter) or reduction in application rate may be appropriate and should be assessed on a case-by-case basis, ideally with site trials.

8.8 Use of CRC as a Sub-base with Unbound Basecourse

When CRC is used as a sub-base below an unbound basecourse, it should be laid out, wet mixed at a target moisture content of 100% of MOMC, compacted, and allowed to dry back (a dryback moisture content below 85% of OMC is suggested) before the basecourse layer is applied. Limiting the dryback period restricts the time available for formation of cementitious bonds and it is therefore expected that the forces generated by compaction of the base layer will induce microcracking in the sub-base. This should reduce the risk of larger and more widely-spaced block cracks occurring, which may then induce cracking in the basecourse.

Where sufficient thickness of unbound basecourse is provided over the CRC sub-base, it is unlikely that cracking in the sub-base will reflect through to the asphalt surface.

8.9 Use of CRC as a Basecourse

If CRC is used as a basecourse it must be used as a sub-base, and a strong interlayer bond must be achieved as discussed in Section 8.4. If this does not occur then a significantly reduced fatigue life of the CRC pavement should be expected.

9 Maintenance and Rehabilitation of CRC Pavements

9.1 Maintenance

As with any pavement, regular maintenance of CRC pavements is required to ensure optimal performance is achieved. Typical maintenance practices such as repair of potholes are not covered in this report. However, maintenance requirements that may be unique to CRC pavements include crack sealing of block cracks and repair of surface blisters.

9.1.1 Crack Sealing

Block cracking of CRC pavements may occur and is not indicative of pavement failure. However, a program of crack sealing should be allowed for to ensure that moisture is kept out of the pavement structure. Provided that waterproofing is maintained, and water does not enter the pavement, good performance should be expected.

As a minimum, annual inspections and crack sealing prior to each wet season should be adopted until the pavement settles down and the rate of block cracking development reduces. This may only be required for the first one to two years but will differ between projects.

Block cracks which occur in CRC pavements may be crack sealed using typical crack sealing techniques. No special crack sealant or techniques are required. However, polymer modified crack sealant products are recommended.

9.1.2 Repair of Surface Blisters

Despite due care being undertaken, impurities which expand and cause blisters in the wearing course may still be present within CRC. Surface blisters which occur should be repaired as required to maintain a smooth wearing surface.

Repair of surface blisters requires patching of the affected area. The asphalt wearing surface should be saw cut and removed, plus the upper portion of the CRC pavement material to ensure that the remaining localised impurities are removed and the issue does not reoccur. The area can then be remediated with an asphalt patch to match the surrounding surface.

9.2 Rehabilitation of CRC pavements

The rehabilitation treatment adopted for CRC pavements should be assessed on a project basis. However, similar rehabilitation approaches to unbound granular pavements are expected to be suitable in most situations. In general, rehabilitation of CRC pavements may comprise:

1. Application of a modified asphalt overlay, such the inclusion of aramid or polyolefin reinforcing fibres within the asphalt.
2. Application of an asphalt reinforcement grid and asphalt overlay.
3. Application of a granular overlay and new wearing course. In urban environments this may not be practical due to level constraints. Depending on the overlay thickness, a crack mitigation layer such as a SAMI may be required.
4. Application of a structural asphalt overlay and new wearing course. In urban environments this may not be practical due to level constraints. Depending on the overlay thickness, a crack mitigation layer such as a SAMI may be required.

5. In situ stabilisation, possibly comprising blending of a cementitious or bituminous binder, and new wearing course. In situ foamed bitumen stabilisation has been effective in rehabilitation of CRC pavements. Depending on the age of the CRC, consideration could be given to omission of crack mitigation treatments, as the majority of the cement within the CRC is expected to have hydrated by this time. UCS testing on samples collected from the pavement should be conducted at an appropriate curing time to assess the block cracking risk for the stabilised pavement.

10 Stakeholder Engagement

10.1 Approach

To optimise the benefit to users of the guideline, engagement with relevant stakeholders was required to better understand the associated issues such as:

- The situations where CRC was being used.
- Barriers to wider adoption of CRC.
- Construction experience.
- Performance of CRC pavements.

The stakeholder engagement comprised two, two-hour workshops with relevant stakeholders. These were held on 5 and 6 March 2024. Separate workshops were held for government and private sector stakeholders.

Prior to each workshop, respondents were provided with a questionnaire. Responses were received from 18 respondents (13 practitioners and five industry). The questionnaire and a summary of the responses are provided in Section 10.3.

Stakeholders were identified by various means to ensure a variety of perspectives. The workshops were attended by representatives from the following organisations:

- Western Australia Local Government Association (primary stakeholder and driver of project).
- National Transport Research Organisation.
- Department of Water and Environmental Regulation.
- Main Roads Western Australia.
- Various Local Governments.
- The Public Transport Authority.
- Waste and Recycling Industry Association of Western Australia.
- Various CRC suppliers.
- Various design consultants.

10.2 Consultation Process

Identified stakeholders were advised of the scheduled workshops via email correspondence. One workshop was conducted for government/public sector stakeholders and a separate workshop was conducted for private sector stakeholders (typically consultants, contractors and suppliers). The two groups of stakeholders were engaged with separately to help encourage open discussion.

The general format of each workshop included:

- Introduction to the LG TRRIP program (WALGA).
- Project overview (NTRO).
- RtR overview (DWER).
- Draft Guideline overview (WSP/CivilSE).
- Discussion of the following general items:
  - Perception of CRC.
  - Supply and logistics.

  - Economics.
  - Construction.
  - Performance.

During the workshop attendees were encouraged to provide responses to various questions via a survey conducted using Mentimeter. The intent of the Mentimeter survey was to encourage discussion rather than provide detailed insights into CRC use and perception. An outlined of the responses is provided in Section 10.3.

10.3 Stakeholder Consultation Outcomes

Written responses were requested from two sources, a Mentimeter survey conducted during each workshop, and a questionnaire provided separately. The outcomes from the stakeholder consultation are provided below.

10.3.1 Workshop Survey (Mentimeter)

Generally, industry participants were more positive towards CRC in pavements, although it is noted that the industry workshop was attended by some CRC suppliers who would be expected to promote the material. However, there was also positivity towards CRC from contractors and design consultants in the industry session. The response from the practitioners' workshop was more neutral to negative towards CRC.

The variation in responses between the two groups might be due to some CRC issues not occurring until later in the pavement life, which practitioners would need to address but contractors and designers may not be aware of, as they would not maintain involvement past the end of a project's defects liability period.

A summary of the main items identified during the workshops is provided below:

- A significant proportion of organisations had experience with CRC; however, the majority of respondents indicated only limited experience with the product.
- RtR accredited suppliers were only indicated to have been used by about half of the respondents for typical CRC projects.
- Most respondents indicated that they would prefer to use RtR accredited suppliers for CRC supply. However, it is noted that this does not correlate with the above response which indicates RtR suppliers had only been used on about half of CRC projects.
- LG respondents generally had a neutral to negative opinion of CRC, while industry respondents were generally positive about the product.
- Sustainability drove the use of CRC in both groups, with economic concerns second. Respondents indicated concern with block cracking, fatigue cracking and dust suppression as reasons not to use CRC.
- The material was reported to be easy to work with but does need to be trimmed before it gains too much strength, otherwise it can be difficult to trim.
- CRC was generally considered to be economic compared with other pavement construction materials. However, LG respondents indicated CRC typically required additional effort to use, adding to project costs. Industry respondents indicated it was easier to work with and reduced overall project costs.
- The availability of CRC varied, with some respondents indicating it was easy to source and others indicating supply was limited or it was not economically viable. There appeared to be variation across projects and regions with supply varying over time.
- The majority of respondents used either IPWEA/WALGA Specification for the Supply of Recycled Road Base or MRWA Specification 501 for CRC.
- Most respondents who conduct pavement design treated CRC as a bound material.

- LG respondents indicated CRC performance typically comparable with other pavement construction materials while industry respondents indicated better performance of CRC pavements.
- LG respondents indicated CRC pavements required additional maintenance compared to other pavement types. This typically required additional monitoring and crack sealing. Industry respondents were asked about maintenance during the defects liability period and advised that CRC pavements typically do not require additional maintenance.

It must be noted that the above comments relate to respondents within the stakeholder workshops and may not be indicative of wider industry trends.

The Mentimeter survey results for the industry and practitioners' workshops are provided in Appendix B.

10.3.2 Stakeholder Questionnaire

Questionnaires were provided to practitioners who responded to the CRC workshop invite. Questionnaire responses were received from the following organisations:

- Government:
    - City of Armadale.
    - City of Busselton.
    - City of Cockburn.
    - City of Gosnells.
    - City of Greater Geraldton.
    - City of Melville.
    - Department of Transport.
    - Shire of Augusta Margaret River.
    - Shire of Carnamah.
    - Shire of East Pilbara.
    - Shire of Esperance.
    - Shire of Merredin.
    - Shire of Murchison.
    - Shire of Serpentine Jarrahdale.
    - Shire of Victoria Plains.
    - Shire of Waroona.
    - Shire of Wongan-Ballidu.
    - Shire of Wyndham East Kimberley.
    - Town of Victoria Park.
- Industry:
    - BG&E Pty Ltd.
    - CMW Geosciences.
    - Corps Group.
    - Laing O'Rourke.
    - WA Limestone.

The questions provided to stakeholders and a summary of the typical responses received is presented in Table 10.1. From the responses it can be seen that there is a wide variety of experience with the material, for example some respondents indicated that CRC had a higher risk than other materials while others indicated it was low risk. However, it is noted that only a single respondent reported issues with pavements constructed using CRC, and most reported that construction of pavements with CRC was generally similar to other pavement construction materials.

Table 10.1: CRC questionnaire and summarised responses

Question	Summary of Stakeholder Responses
Have you used CRC on any projects?	There were a mix of responses; however, in general respondents within the metropolitan area and larger regional areas (such as Karratha) had used CRC, while practitioners in more remote regional areas had not.
If not, why have you not used it?	For those that had not used CRC it was generally due to lack of supply, unfamiliarity with the material, marginal cost benefits, or the perceived risk associated with CRC. Regional practitioners in particular indicated that supply was limited or uneconomical.
If yes, what made you select CRC over other materials?	For those that had used CRC the reasons for selecting this product included reduced cost, improved performance, availability of crushing of source material, design consultant recommendations and benefits to pavement design such as being able to reduce FDA thickness on MRWA projects.
How did you specify the CRC materials? Please list any specifications used if known.	Engineering specifications used for CRC typically included MRWA Specification 501 (Pavements) and Specification 302 (Earthworks, for subgrade improvement layers), and IPWEA/WALGA Specification for the Supply of Recycled Road Base. Practitioners generally did not indicate that they used bespoke engineering specifications for CRC.
What is your perception regarding the number of CRC suppliers, and how available is CRC?	There appears to be limited supply of CRC in the regions, and historically some respondents indicated issues with supply in the metropolitan area. However, CRC was generally indicated to be available in the metropolitan area.
Was CRC cost competitive?	Respondents generally indicated that CRC was cost competitive compared to alternative pavement construction materials. However, it is noted that due to the nature of supply and demand for CRC being variable, depending on what demolition works and construction projects are ongoing at any one time, the cost of the material compared with alternatives may vary.
Was it sourced from a RtR accredited supplier? Why did you use/not use an RtR accredited supplier?	Respondents located in regional areas generally did not use RtR accredited suppliers as none were available. Within the metropolitan area some respondents had used RtR accredited suppliers but a number were not sure, as they left sourcing of materials up to the contractor engaged for each project.
Where did you use it – local streets, distributor roads, paths etc.?	CRC was indicated to have been used for pavements comprising hardstands, car parks, local streets and distributor roads. It has also been used for temporary works. Two regions indicated they blended it with gravel. The blended material was indicated to be suitable for unsealed shoulders.
What pavement layer – e.g. basecourse, sub-base, improved subgrade?	CRC has been used for subgrade improvement, sub-base and basecourse layers.
What method of pavement design was used to determine layer thickness?	A variety of responses was received for this query which included direct replacement of granular material (*i.e.* no specialised design), the empirical method and the mechanistic-empirical method using CIRCLY software.
Have you had any problems with performance, for example cracking or blistering of the surface? Were these problems expected and did they affect performance of the asset?	One respondent indicated problems with blistering, cracking and issues associated with airborne dust. One response indicated concerns with pickup of a SAMI with a high bitumen application rate under an asphalt paver, although this is not considered to be related to the use of CRC directly.
Did any issues occur that might prevent you from using CRC on future projects? If so, what were they and why might they affect use of CRC on future projects?	Generally most respondents did not indicate issues which would prevent the use of CRC in future projects. General concerns raised related to the cost of the material and/or haulage in regional areas. One respondent indicated issues associated with impurities such as metals, plastic and organics. One responded indicated issues associated with blistering, cracking and dust would prevent them from using the material.

Question	Summary of Stakeholder Responses
How did the haulage distance compare with alternative materials?	Haulage distances were not indicated to be an issue apart from regional areas where suppliers may be limited.
Were there any issues with the material achieving the project specification requirements for physical properties (such as grading, CBR, material constituents, etc.)? If so, what were they?	Respondents generally indicated that the CRC achieved the specification requirements. One respondent indicated concerns about the material being too clayey if it was blended with too much crushed brick and tile.
Was the material easy to work (lay out, moisture condition and compact)?	CRC was almost unanimously indicated to be easy to work with on site. It was typically comparable to alternative pavement construction materials. One respondent indicated mixing and spreading CRC took slightly longer than crushed limestone sub-base.
Was the material easy to trim with a grader? Was it trimmed shortly after construction or allowed to dry out/cure?	Trimming was generally indicated to be comparable to other materials if conducted before significant strength gain from rehydration occurred. It was noted that CRC can wear down grader blades more quickly than other materials if allowed to harden prior to trimming.
Was the surface finish of CRC generally better or worse than other materials following trimming? If worse, in what way?	Generally, the surface finish was indicated to be comparable to crushed rock base and better than crushed limestone sub-base. One respondent indicated some segregation near the edges of the pavement. However, this may not be specific to CRC and could relate to the construction process.
Did the use of CRC affect other pavement layers? For example, did you omit a prime or seal coat where these would otherwise be applied?	Using CRC typically did not affect other pavement layers.
Did using CRC have any effect on the construction schedule? E.g. did it dry back faster than alternative materials?	Some respondents indicated that CRC helped speed up the construction process, while others indicated no difference. No respondents indicated that CRC hampered construction, although one indicated difficulties achieving dryback in cooler conditions.

11 Further Research

While the use of CRC for construction of granular pavements is increasing in WA, there are areas where further research on the performance of CRC pavements would help to manage risk. In particular, the following potential research areas which relate to this report have been identified:

11.1 CRC Cost Variability

Anecdotal evidence suggests that the cost of CRC can vary between projects. In particular, large infrastructure projects with high demand for CRC can consume a significant proportion of supply and put upwards pressure on prices. Further work to understand the CRC supply chain constraints, lead times, *etc*. and improve consistency of supply may help to reduce price volatility.

11.2 Flexural Modulus of CRC

The flexural modulus of CRC is a required input into bound pavement design (where CRC is used as a basecourse and sub-base in this report). While CRC is a variable material as it typically comprises material from different sources, testing to assess the flexural modulus would help to inform bound pavement design. If sufficient CRC materials are tested this would allow statistical assessment of the typical values achieved for CRC.

The flexural modulus of 2,000 MPa adopted for CRC for the pavement designs presented in this report may be conservative. Testing of various CRC sources at various stages of curing (up to 12 months preferably) would allow a more appropriate flexural modulus to be adopted for bound pavement designs using CRC.

11.3 Blending of CRC

The effect of blending CRC with non-cementitious materials, such as crushed brick and tile or crushed rock base, on the UCS and hence performance of CRC pavements in relation to block cracking has not been widely explored. While some trials using blended material have been conducted (refer Section 4.2, Trial Section 4), detailed research does not appear to be available.

Cocks *et al* (2017) indicated that blending CRC did not have a significant effect on the UCS of the materials, but only two materials were used for blending (crushed brick and tile, and ferricrete).

Further exploration on the use of blending to manage the UCS of CRC pavement materials and block cracking risk would help to determine if blending can be used to manage the risk of block cracking, and if this is the case it may allow practitioners to remove the requirement for other crack mitigation measures and reduce overall pavement construction costs.

This research is currently underway by Murdoch University students.

11.4 Asphalt Geogrid Reinforcement

Asphalt geogrids as a crack mitigation treatment below thin asphalt wearing courses have not been widely adopted in WA. Anecdotal evidence and experience in other locations in Australia suggests that geogrids can reduce the occurrence of reflection cracking in asphalt wearing courses. However, suppliers of asphalt geogrids have indicated that they require both an asphalt surface to place the geogrid on (either milled existing asphalt or new asphalt), and a minimum of about 50 mm asphalt overlying the geogrid, for them to provide a warranty for the performance of their product. This is not practical for LG applications which might require the geogrid to be applied directly to a primed CRC basecourse (with geogrid bond coat) for the approach to be cost effective.

Further assessment of the performance of asphalt geogrids placed over various surfaces, such as primed CRC or primed CRC with a bituminous seal, and with reduced thickness of overlying asphalt may help to encourage wider adoption in local government applications.

11.5 Crumb Rubber, Polymer Modified or Fibre Reinforced Asphalt

Limited anecdotal evidence suggests that the use of crumb rubber modified asphalt may help to reduce the occurrence of block cracking (GeoPave 1997). The authors consider it reasonable to infer that this would also suggest that the inclusion of polymer modified bitumen within asphalt may also help to reduce the occurrence of refection cracking. However, it must be noted that the reported benefits used an asphalt mix containing about 8% bitumen and 2.7% crumb rubber, which is significantly higher than asphalt mixes commonly available at the date of this report.

Further assessment of the benefits of crumb rubber or polymer modified asphalt at more common bitumen contents of around 5% would be beneficial. If these asphalt mixes are successful in reducing the occurrence of block cracking, then practitioners may be able to remove other crack mitigation layers from their pavement designs.

The City of Canning has had promising results from the inclusion of aramid and polyolefin reinforcing fibres within wearing course asphalt over significantly cracked stabilised pavements. Fibre reinforcement of asphalt is not typically undertaken in WA and may be a suitable option for rehabilitation of cracked pavements.

References

ARRB (2010), Contract Report, Specification and Performance of Recycled Materials in Road Pavements, 001119-1, Australian Road Research Board, July 2010.

ARRB (2020), Road Materials Best Practice Guide 1, Australian Road Research Board, May 2020.

ARRB (2022), Best Practice Expert Advice on the Use of Recycled Materials in Road and Rail Infrastructure: Part A Technical Review and Assessment, Australian Road Research Board, June 2022.

Austroads (2000), Use of Recycled Materials and the Management of Roadside Vegetation on Low Trafficked Roads, Austroads Publication No. AP-R154/00, 2000.

Austroads (2012), Guide to Pavement Technology Part 2: Pavement Structural Design, Austroads Publication No. AGPT02-12, February 2012.

Austroads (2017), Guide to Pavement Technology Part 2: Pavement Structural Design, Austroads Publication No. AGPT02-17, Edition 4.2, October 2018.

Austroads (2018), Guide to Pavement Technology Part 4K, Selection and Design of Sprayed Seals, Austroads Publication No. AGPT04K-18, Edition 1.3, November 2019.

Austroads (2019), Guide to Pavement Technology Part 4D: Stabilised Materials, Austroads Publication No. AGPT04D-19, Edition 2.0, March 2019.

Austroads (2022), Guide to Pavement Technology Part 4E: Recycled Materials, Austroads Publication No. AGPT04E-22, July 2022

Austroads (2022a), Technical Basis of Guide to Pavement Technology Part 4E: Recycled Materials, Austroads Publication No. AP-T365-22, April 2022

Cocks, G., Leek, C., Bondietti, M., Hossein, A., Deilami, S., Leach, R., Sicoe, M., Clayton, R., Keeley, R., Maekivi, C. (2017), The Use of Recycled Materials for Pavements in Western Australia, Australian Geomechanics Vol. 52, No. 1, March 2017.

Department for Infrastructure and Transport, Roads Master Specification, RD-PV-S1 Supply of Pavement Materials, Version 4, July 2022.

DWER (2020), Roads to Reuse Pilot Project, Waste Authority of Western Australia c/o Department of Water and Environmental Regulation, November 2020

GeoPave (1997), Technical Note 20, Reducing Reflection Cracking over Jointed Concrete Pavement, September 1997.

IPWEA (NSW) Roads and Transport Directorate (2010), Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage, Institute of Public Works Engineers Australia (NSW), Issue No. 2.0, April 2010.

IPWEA (2016), Local Government Guidelines for Subdivisional Development, Edition 2.3, November 2017.

IPWEA/WALGA (2016), Specification for the Supply of Recycled Road Base, Institute of Public Works Engineers Australia, May 2016.

L5D (2021), SWA Innovation Hub, Potential Waste Opportunity – Construction & Demolition Waste (Crushed Recycled Concrete) Material, Companion Document to Technical Specifications, Level 5 Design Pty Ltd, 17 September 2021.

Leek, C., Siripun, K., Nikraz, H. & Jitsangiam, P. (2011), An Investigation into the Performance of Recycled Concrete Aggregate as a Base Course Material in Road Pavements, International Conference on Advances in Geotechnical Engineering, Perth, Australia, 7-9 November 2011.

Mehta, P.K. (1987). "Natural pozzolans: Supplementary cementing materials in concrete". CANMET Special Publication. 86: 1–33

MRWA (2013), Engineering Road Note 9, Procedure for the design of road pavements, Western Australian Supplement to the Austroads Guide to Pavement Technology Part 2: Pavement Structural Design, May 2013.

MRWA (2020), Repeat Load Triaxial (RLT) Testing Results for Granular Basecourse and Sub-base Materials, Materials Engineering, Report No. 2019-9M/1, 14 December 2020.

MRWA (2022), Recycled and Sustainable Materials at Main Roads, Reference Guide, Document No. D21#12639, November 2022

MRWA (2023), Specification 501 – Pavements, Main Roads Western Australia, 10 May 2023.

PTA (2023), Specification, Roads, Busways, Paths and Access Tracks, 8880-450-067, Rev 2.02, 11 October 2023.

SASA (unknown year), Investigation of Popping in Thin Asphalt Surfaces, Environmental Fact Sheet No. 4, Sustainable Aggregates South Australia.

TfNSW (2020), QA Specification 3051, Granular Pavement Base and Sub-base Materials, IC-QA-3051, Edition 7/Revision 1, Transport for New South Wales, 22 June 2020.

TMR (2020), Technical Note TN193, Use of Recycled Materials in Road Construction, Department of Transport and Main Roads, September 2020.

TMR (2022), Technical Specification MRTS05 Unbound Pavements, Department of Transport and Main Roads, July 2022.

VicRoads (2022), Section 820 – Crushed Concrete for Pavement Sub-base and Light Duty Base, April 2011.

VicRoads (2023), Technical Note 107, Use of Recycled Materials in Road Pavements, Version 3.0, July 2023.

Waste Authority WA (2021), Roads to Reuse Product Specification – Recycled Road Base and Recycled Drainage Rock, Waste Authority of Western Australia, March 2021

Appendix A CIRCLY Design Sheets

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CIRCLY  - Version 6.0 (12 April 2021)

Job Title: PS204422 NTRO CRC Construction Guide

Damage Factor Calculation

Assumed number of damage pulses per movement:
   Combined pulse for gear (i.e. ignore NROWS)

Traffic Spectrum Details:

   Load   Load                   Movements
   No.    ID
    1     ESA750-Full            1.00E+06

Details of Load Groups:

   Load   Load                  Load                  Load            Radius    Pressure/    Exponent
   No.    ID                    Category              Type                      Ref. stress
    1     ESA750-Full           ESA750-Full           Vertical Force     92.1    0.75         0.00

   Load Locations:
   Location   Load                  Gear          X          Y      Scaling     Theta
   No.        ID                    No.                             Factor
    1         ESA750-Full            1          -165.0        0.0   1.00E+00      0.00
    2         ESA750-Full            1           165.0        0.0   1.00E+00      0.00
    3         ESA750-Full            1          1635.0        0.0   1.00E+00      0.00
    4         ESA750-Full            1          1965.0        0.0   1.00E+00      0.00

Layout of result points on horizontal plane:
   Xmin:  0   Xmax:  165   Xdel:  165
   Y:     0

Details of Layered System:

   ID: PS204422a Title: CRC Pavement Profiles

   Layer  Lower    Material               Isotropy   Modulus    P.Ratio
   No.    i/face   ID                                (or Ev)    (or vvh)  F          Eh         vh
    1     rough    115005P-02             Iso.       2.19E+03   0.40
    2     rough    Cement2000             Iso.       2.00E+03   0.20
    3     rough    Sub_CBR5               Aniso.     5.00E+01   0.45      3.45E+01   2.50E+01   0.45

   Performance Relationships:
   Layer  Location Material               Component  Perform.   Perform.  Traffic
   No.             ID                                Constant   Exponent  Multiplier
    1     bottom   115005P-02             ETH         0.004852    5.000     1.130
    2     bottom   Cement2000             ETH         0.000442   12.000     9.780
    3     top      Sub_CBR5               EZZ         0.009300    7.000     1.640

   Reliability Factors:
   Project Reliability: Austroads 95%
   Layer  Reliability  Material
    No.   Factor       Type
    1      1.00       Asphalt
    2      1.00       Cement Stabilised
    3      1.00       Subgrade (Austroads 2004)


Results:

   Layer  Thickness  Material               Load                   Critical       CDF
   No.               ID                     ID                     Strain
    1       30.00    115005P-02             ESA750-Full             1.31E-05      1.13E-31
    2      355.00    Cement2000             ESA750-Full            -1.14E-04      8.30E-01
    3        0.00    Sub_CBR5               ESA750-Full             2.72E-04      3.03E-05
```

```
CIRCLY  - Version 6.0 (12 April 2021)

Job Title: PS204422 NTRO CRC Construction Guide

Damage Factor Calculation

Assumed number of damage pulses per movement:
   Combined pulse for gear (i.e. ignore NROWS)

Traffic Spectrum Details:

   Load   Load                   Movements
   No.    ID
    1     ESA750-Full            3.00E+06

Details of Load Groups:

   Load   Load                  Load                  Load            Radius    Pressure/    Exponent
   No.    ID                    Category              Type                      Ref. stress
    1     ESA750-Full           ESA750-Full           Vertical Force     92.1    0.75         0.00

   Load Locations:
   Location   Load                  Gear          X          Y      Scaling     Theta
   No.        ID                    No.                             Factor
    1         ESA750-Full            1         -165.0        0.0   1.00E+00      0.00
    2         ESA750-Full            1          165.0        0.0   1.00E+00      0.00
    3         ESA750-Full            1         1635.0        0.0   1.00E+00      0.00
    4         ESA750-Full            1         1965.0        0.0   1.00E+00      0.00

Layout of result points on horizontal plane:
   Xmin:  0   Xmax:  165   Xdel:  165
   Y:     0

Details of Layered System:

   ID: PS204422a Title: CRC Pavement Profiles

   Layer  Lower    Material               Isotropy   Modulus    P.Ratio
   No.    i/face   ID                                (or Ev)    (or vvh)  F          Eh         vh
    1     rough    115005P-02             Iso.       2.19E+03   0.40
    2     rough    Cement2000             Iso.       2.00E+03   0.20
    3     rough    Sub_CBR5               Aniso.     5.00E+01   0.45      3.45E+01   2.50E+01   0.45

   Performance Relationships:
   Layer  Location Material               Component  Perform.   Perform.  Traffic
   No.             ID                                Constant   Exponent  Multiplier
    1     bottom   115005P-02             ETH         0.004852    5.000     1.130
    2     bottom   Cement2000             ETH         0.000442   12.000     9.780
    3     top      Sub_CBR5               EZZ         0.009300    7.000     1.640

   Reliability Factors:
   Project Reliability: Austroads 95%
   Layer  Reliability  Material
    No.   Factor       Type
    1      1.00       Asphalt
    2      1.00       Cement Stabilised
    3      1.00       Subgrade (Austroads 2004)


Results:

   Layer  Thickness  Material               Load                    Critical       CDF
   No.               ID                     ID                      Strain
    1       30.00    115005P-02             ESA750-Full              1.09E-05      3.39E-31
    2      375.00    Cement2000             ESA750-Full             -1.05E-04      9.91E-01
    3        0.00    Sub_CBR5               ESA750-Full              2.53E-04      5.40E-05
```

```
CIRCLY  - Version 6.0 (12 April 2021)

Job Title: PS204422 NTRO CRC Construction Guide

Damage Factor Calculation

Assumed number of damage pulses per movement:
   Combined pulse for gear (i.e. ignore NROWS)

Traffic Spectrum Details:

   Load   Load                   Movements
   No.    ID
    1     ESA750-Full            1.00E+07

Details of Load Groups:

   Load   Load                  Load                  Load            Radius    Pressure/    Exponent
   No.    ID                    Category              Type                      Ref. stress
    1     ESA750-Full           ESA750-Full           Vertical Force     92.1    0.75         0.00

   Load Locations:
   Location   Load                  Gear          X          Y      Scaling     Theta
   No.        ID                    No.                             Factor
    1         ESA750-Full            1         -165.0        0.0   1.00E+00      0.00
    2         ESA750-Full            1          165.0        0.0   1.00E+00      0.00
    3         ESA750-Full            1         1635.0        0.0   1.00E+00      0.00
    4         ESA750-Full            1         1965.0        0.0   1.00E+00      0.00

Layout of result points on horizontal plane:
   Xmin:  0   Xmax:  165   Xdel:  165
   Y:     0

Details of Layered System:

   ID: PS204422a Title: CRC Pavement Profiles

   Layer  Lower    Material               Isotropy   Modulus    P.Ratio
   No.    i/face   ID                                (or Ev)    (or vvh)  F          Eh         vh
    1     rough    115005P-02             Iso.       2.19E+03   0.40
    2     rough    Cement2000             Iso.       2.00E+03   0.20
    3     rough    Sub_CBR5               Aniso.     5.00E+01   0.45      3.45E+01   2.50E+01   0.45

   Performance Relationships:
   Layer  Location Material               Component  Perform.   Perform.  Traffic
   No.             ID                                Constant   Exponent  Multiplier
    1     bottom   115005P-02             ETH         0.004852    5.000     1.130
    2     bottom   Cement2000             ETH         0.000442   12.000     9.780
    3     top      Sub_CBR5               EZZ         0.009300    7.000     1.640

   Reliability Factors:
   Project Reliability: Austroads 95%
   Layer  Reliability  Material
    No.   Factor        Type
    1      1.00       Asphalt
    2      1.00       Cement Stabilised
    3      1.00       Subgrade (Austroads 2004)


Results:

   Layer  Thickness  Material                Load                    Critical       CDF
   No.               ID                      ID                      Strain
    1       30.00    115005P-02              ESA750-Full              8.12E-06      1.13E-30
    2      405.00    Cement2000              ESA750-Full             -9.44E-05      8.90E-01
    3        0.00    Sub_CBR5                ESA750-Full              2.27E-04      8.59E-05
```

```
CIRCLY  - Version 6.0 (12 April 2021)

Job Title: PS204422 NTRO CRC Construction Guide

Damage Factor Calculation

Assumed number of damage pulses per movement:
   Combined pulse for gear (i.e. ignore NROWS)

Traffic Spectrum Details:

   Load   Load                   Movements
   No.    ID
    1     ESA750-Full            1.00E+06

Details of Load Groups:

   Load   Load                  Load                  Load           Radius    Pressure/    Exponent
   No.    ID                    Category              Type                     Ref. stress
    1     ESA750-Full           ESA750-Full           Vertical Force     92.1    0.75         0.00

   Load Locations:
   Location   Load                  Gear          X          Y      Scaling     Theta
   No.        ID                    No.                             Factor
    1         ESA750-Full            1         -165.0        0.0   1.00E+00      0.00
    2         ESA750-Full            1          165.0        0.0   1.00E+00      0.00
    3         ESA750-Full            1         1635.0        0.0   1.00E+00      0.00
    4         ESA750-Full            1         1965.0        0.0   1.00E+00      0.00

Layout of result points on horizontal plane:
   Xmin:  0   Xmax:  165   Xdel:  165
   Y:     0

Details of Layered System:

   ID: PS204422a Title: CRC Pavement Profiles

   Layer  Lower    Material               Isotropy   Modulus    P.Ratio
   No.    i/face   ID                                (or Ev)    (or vvh)  F          Eh         vh
    1     rough    115005P-02             Iso.       2.19E+03   0.40
    2     rough    Cement2000             Iso.       2.00E+03   0.20
    3     rough    Sub_CBR8               Aniso.     8.00E+01   0.45      5.52E+01   4.00E+01   0.45

   Performance Relationships:
   Layer  Location Material               Component  Perform.   Perform.  Traffic
   No.             ID                                Constant   Exponent  Multiplier
    1     bottom   115005P-02             ETH         0.004852    5.000     1.130
    2     bottom   Cement2000             ETH         0.000442   12.000     9.780
    3     top      Sub_CBR8               EZZ         0.009300    7.000     1.640

   Reliability Factors:
   Project Reliability: Austroads 95%
   Layer  Reliability  Material
    No.   Factor       Type
    1      1.00       Asphalt
    2      1.00       Cement Stabilised
    3      1.00       Subgrade (Austroads 2004)


Results:

   Layer  Thickness  Material               Load                   Critical       CDF
   No.               ID                     ID                     Strain
    1       30.00    115005P-02             ESA750-Full             1.10E-05      1.13E-31
    2      320.00    Cement2000             ESA750-Full            -1.14E-04      8.88E-01
    3        0.00    Sub_CBR8               ESA750-Full             2.58E-04      2.08E-05
```

```
CIRCLY  - Version 6.0 (12 April 2021)

Job Title: PS204422 NTRO CRC Construction Guide

Damage Factor Calculation

Assumed number of damage pulses per movement:
   Combined pulse for gear (i.e. ignore NROWS)

Traffic Spectrum Details:

   Load   Load                   Movements
   No.    ID
    1     ESA750-Full             3.00E+06

Details of Load Groups:

   Load   Load                  Load                  Load            Radius    Pressure/    Exponent
   No.    ID                    Category              Type                      Ref. stress
    1     ESA750-Full           ESA750-Full           Vertical Force     92.1    0.75         0.00

   Load Locations:
   Location   Load                  Gear          X          Y      Scaling     Theta
   No.        ID                    No.                             Factor
    1         ESA750-Full            1          -165.0        0.0   1.00E+00      0.00
    2         ESA750-Full            1           165.0        0.0   1.00E+00      0.00
    3         ESA750-Full            1          1635.0        0.0   1.00E+00      0.00
    4         ESA750-Full            1          1965.0        0.0   1.00E+00      0.00

Layout of result points on horizontal plane:
   Xmin:  0   Xmax:  165   Xdel:  165
   Y:     0

Details of Layered System:

   ID: PS204422a Title: CRC Pavement Profiles

   Layer  Lower    Material               Isotropy   Modulus    P.Ratio
   No.    i/face   ID                                (or Ev)    (or vvh)  F          Eh         vh
    1     rough    115005P-02             Iso.       2.19E+03   0.40
    2     rough    Cement2000             Iso.       2.00E+03   0.20
    3     rough    Sub_CBR8               Aniso.     8.00E+01   0.45      5.52E+01   4.00E+01   0.45

   Performance Relationships:
   Layer  Location Material               Component  Perform.   Perform.  Traffic
   No.             ID                                Constant   Exponent  Multiplier
    1     bottom   115005P-02             ETH         0.004852    5.000     1.130
    2     bottom   Cement2000             ETH         0.000442   12.000     9.780
    3     top      Sub_CBR8               EZZ         0.009300    7.000     1.640

   Reliability Factors:
   Project Reliability: Austroads 95%
   Layer  Reliability  Material
    No.   Factor        Type
    1      1.00       Asphalt
    2      1.00       Cement Stabilised
    3      1.00       Subgrade (Austroads 2004)


Results:

   Layer  Thickness  Material               Load                     Critical       CDF
   No.               ID                     ID                       Strain
    1       30.00    115005P-02             ESA750-Full               8.75E-06      3.39E-31
    2      340.00    Cement2000             ESA750-Full              -1.05E-04      9.90E-01
    3        0.00    Sub_CBR8               ESA750-Full               2.38E-04      3.58E-05
```

```
CIRCLY  - Version 6.0 (12 April 2021)

Job Title: PS204422 NTRO CRC Construction Guide

Damage Factor Calculation

Assumed number of damage pulses per movement:
   Combined pulse for gear (i.e. ignore NROWS)

Traffic Spectrum Details:

   Load   Load                   Movements
   No.    ID
    1     ESA750-Full            1.00E+07

Details of Load Groups:

   Load   Load                  Load                  Load            Radius    Pressure/    Exponent
   No.    ID                    Category              Type                      Ref. stress
    1     ESA750-Full           ESA750-Full           Vertical Force     92.1    0.75         0.00

   Load Locations:
   Location   Load                  Gear          X          Y      Scaling     Theta
   No.        ID                    No.                             Factor
    1         ESA750-Full            1          -165.0        0.0   1.00E+00      0.00
    2         ESA750-Full            1           165.0        0.0   1.00E+00      0.00
    3         ESA750-Full            1          1635.0        0.0   1.00E+00      0.00
    4         ESA750-Full            1          1965.0        0.0   1.00E+00      0.00

Layout of result points on horizontal plane:
   Xmin:  0   Xmax:  165   Xdel:  165
   Y:     0

Details of Layered System:

   ID: PS204422a Title: CRC Pavement Profiles

   Layer  Lower    Material               Isotropy   Modulus    P.Ratio
   No.    i/face   ID                                (or Ev)    (or vvh)  F          Eh          vh
    1     rough    115005P-02             Iso.       2.19E+03   0.40
    2     rough    Cement2000             Iso.       2.00E+03   0.20
    3     rough    Sub_CBR8               Aniso.     8.00E+01   0.45      5.52E+01   4.00E+01   0.45

   Performance Relationships:
   Layer  Location Material               Component  Perform.   Perform.  Traffic
   No.             ID                                Constant   Exponent  Multiplier
    1     bottom   115005P-02             ETH         0.004852    5.000     1.130
    2     bottom   Cement2000             ETH         0.000442   12.000     9.780
    3     top      Sub_CBR8               EZZ         0.009300    7.000     1.640

   Reliability Factors:
   Project Reliability: Austroads 95%
   Layer  Reliability  Material
    No.   Factor       Type
    1      1.00       Asphalt
    2      1.00       Cement Stabilised
    3      1.00       Subgrade (Austroads 2004)


Results:

   Layer  Thickness  Material               Load                    Critical       CDF
   No.               ID                     ID                      Strain
    1       30.00    115005P-02             ESA750-Full              5.78E-06      1.13E-30
    2      370.00    Cement2000             ESA750-Full             -9.36E-05      8.08E-01
    3        0.00    Sub_CBR8               ESA750-Full              2.13E-04      5.39E-05
```

```
CIRCLY  - Version 6.0 (12 April 2021)

Job Title: PS204422 NTRO CRC Construction Guide

Damage Factor Calculation

Assumed number of damage pulses per movement:
   Combined pulse for gear (i.e. ignore NROWS)

Traffic Spectrum Details:

   Load   Load                   Movements
   No.    ID
    1     ESA750-Full            1.00E+06

Details of Load Groups:

   Load   Load                  Load                  Load            Radius    Pressure/    Exponent
   No.    ID                    Category              Type                      Ref. stress
    1     ESA750-Full           ESA750-Full           Vertical Force     92.1    0.75         0.00

   Load Locations:
   Location   Load                  Gear          X          Y      Scaling     Theta
   No.        ID                    No.                             Factor
    1         ESA750-Full            1         -165.0        0.0   1.00E+00      0.00
    2         ESA750-Full            1          165.0        0.0   1.00E+00      0.00
    3         ESA750-Full            1         1635.0        0.0   1.00E+00      0.00
    4         ESA750-Full            1         1965.0        0.0   1.00E+00      0.00

Layout of result points on horizontal plane:
   Xmin:  0   Xmax:  165   Xdel:  165
   Y:     0

Details of Layered System:

   ID: PS204422a Title: CRC Pavement Profiles

   Layer  Lower    Material               Isotropy   Modulus    P.Ratio
   No.    i/face   ID                                (or Ev)    (or vvh)  F          Eh         vh
    1     rough    115005P-02             Iso.       2.19E+03   0.40
    2     rough    Cement2000             Iso.       2.00E+03   0.20
    3     rough    Sub_CBR12              Aniso.     1.20E+02   0.35      8.89E+01   6.00E+01   0.35

   Performance Relationships:
   Layer  Location Material               Component  Perform.   Perform.  Traffic
   No.             ID                                Constant   Exponent  Multiplier
    1     bottom   115005P-02             ETH         0.004852    5.000     1.130
    2     bottom   Cement2000             ETH         0.000442   12.000     9.780
    3     top      Sub_CBR12              EZZ         0.009300    7.000     1.640

   Reliability Factors:
   Project Reliability: Austroads 95%
   Layer  Reliability  Material
    No.   Factor       Type
    1      1.00       Asphalt
    2      1.00       Cement Stabilised
    3      1.00       Subgrade (Austroads 2004)


Results:

   Layer  Thickness  Material               Load                     Critical       CDF
   No.               ID                     ID                       Strain
    1       30.00    115005P-02             ESA750-Full               1.00E-05      1.13E-31
    2      285.00    Cement2000             ESA750-Full              -1.14E-04      8.61E-01
    3        0.00    Sub_CBR12              ESA750-Full               2.79E-04      3.56E-05
```

```
CIRCLY  - Version 6.0 (12 April 2021)

Job Title: PS204422 NTRO CRC Construction Guide

Damage Factor Calculation

Assumed number of damage pulses per movement:
   Combined pulse for gear (i.e. ignore NROWS)

Traffic Spectrum Details:

   Load   Load                   Movements
   No.    ID
    1     ESA750-Full            3.00E+06

Details of Load Groups:

   Load   Load                  Load                  Load            Radius    Pressure/    Exponent
   No.    ID                    Category              Type                      Ref. stress
    1     ESA750-Full           ESA750-Full           Vertical Force     92.1    0.75         0.00

   Load Locations:
   Location   Load                  Gear          X          Y      Scaling     Theta
   No.        ID                    No.                              Factor
    1         ESA750-Full            1          -165.0        0.0   1.00E+00      0.00
    2         ESA750-Full            1           165.0        0.0   1.00E+00      0.00
    3         ESA750-Full            1          1635.0        0.0   1.00E+00      0.00
    4         ESA750-Full            1          1965.0        0.0   1.00E+00      0.00

Layout of result points on horizontal plane:
   Xmin:  0   Xmax:  165   Xdel:  165
   Y:     0

Details of Layered System:

   ID: PS204422a Title: CRC Pavement Profiles

   Layer  Lower    Material               Isotropy   Modulus    P.Ratio
   No.    i/face   ID                                (or Ev)    (or vvh)  F          Eh         vh
    1     rough    115005P-02             Iso.       2.19E+03   0.40
    2     rough    Cement2000             Iso.       2.00E+03   0.20
    3     rough    Sub_CBR12              Aniso.     1.20E+02   0.35      8.89E+01   6.00E+01   0.35

   Performance Relationships:
   Layer  Location Material               Component  Perform.   Perform.  Traffic
   No.             ID                                Constant   Exponent  Multiplier
    1     bottom   115005P-02             ETH         0.004852    5.000     1.130
    2     bottom   Cement2000             ETH         0.000442   12.000     9.780
    3     top      Sub_CBR12              EZZ         0.009300    7.000     1.640

   Reliability Factors:
   Project Reliability: Austroads 95%
   Layer  Reliability  Material
    No.   Factor       Type
    1      1.00       Asphalt
    2      1.00       Cement Stabilised
    3      1.00       Subgrade (Austroads 2004)


Results:

   Layer  Thickness  Material                Load                    Critical       CDF
   No.               ID                      ID                      Strain
    1       30.00    115005P-02              ESA750-Full              7.65E-06      3.39E-31
    2      305.00    Cement2000              ESA750-Full             -1.04E-04      8.95E-01
    3        0.00    Sub_CBR12               ESA750-Full              2.56E-04      5.88E-05
```

```
CIRCLY  - Version 6.0 (12 April 2021)

Job Title: PS204422 NTRO CRC Construction Guide

Damage Factor Calculation

Assumed number of damage pulses per movement:
   Combined pulse for gear (i.e. ignore NROWS)

Traffic Spectrum Details:

   Load   Load                   Movements
   No.    ID
    1     ESA750-Full            1.00E+07

Details of Load Groups:

   Load   Load                  Load                  Load            Radius    Pressure/    Exponent
   No.    ID                    Category              Type                      Ref. stress
    1     ESA750-Full           ESA750-Full           Vertical Force     92.1    0.75         0.00

   Load Locations:
   Location   Load                  Gear          X          Y      Scaling     Theta
   No.        ID                    No.                             Factor
    1         ESA750-Full            1         -165.0        0.0   1.00E+00      0.00
    2         ESA750-Full            1          165.0        0.0   1.00E+00      0.00
    3         ESA750-Full            1         1635.0        0.0   1.00E+00      0.00
    4         ESA750-Full            1         1965.0        0.0   1.00E+00      0.00

Layout of result points on horizontal plane:
   Xmin:  0   Xmax:  165   Xdel:  165
   Y:     0

Details of Layered System:

   ID: PS204422a Title: CRC Pavement Profiles

   Layer  Lower    Material               Isotropy   Modulus    P.Ratio
   No.    i/face   ID                                (or Ev)    (or vvh)  F          Eh         vh
    1     rough    115005P-02             Iso.       2.19E+03   0.40
    2     rough    Cement2000             Iso.       2.00E+03   0.20
    3     rough    Sub_CBR12              Aniso.     1.20E+02   0.35      8.89E+01   6.00E+01   0.35

   Performance Relationships:
   Layer  Location Material               Component  Perform.   Perform.  Traffic
   No.             ID                                Constant   Exponent  Multiplier
    1     bottom   115005P-02             ETH         0.004852    5.000     1.130
    2     bottom   Cement2000             ETH         0.000442   12.000     9.780
    3     top      Sub_CBR12              EZZ         0.009300    7.000     1.640

   Reliability Factors:
   Project Reliability: Austroads 95%
   Layer  Reliability  Material
    No.   Factor       Type
    1      1.00       Asphalt
    2      1.00       Cement Stabilised
    3      1.00       Subgrade (Austroads 2004)


Results:

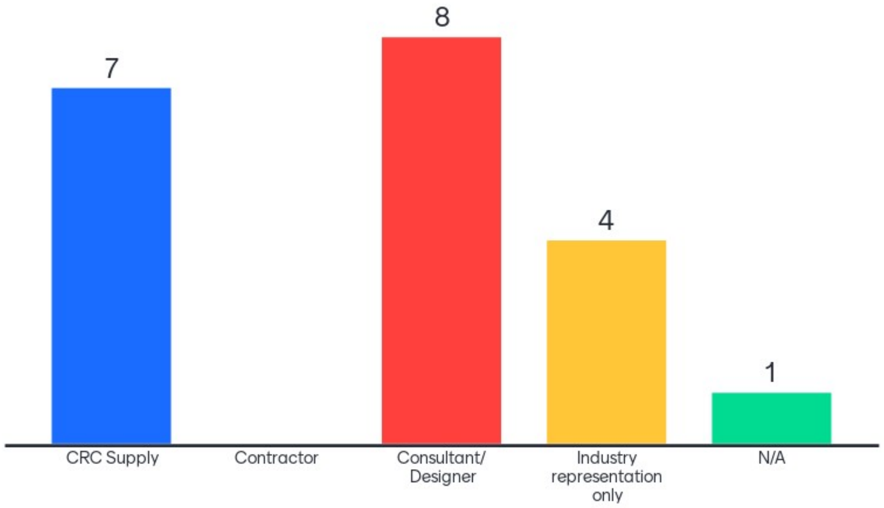
   Layer  Thickness  Material               Load                    Critical       CDF
   No.               ID                     ID                      Strain
    1       30.00    115005P-02             ESA750-Full              5.01E-06      1.13E-30
    2      330.00    Cement2000             ESA750-Full             -9.40E-05      8.45E-01
    3        0.00    Sub_CBR12              ESA750-Full              2.31E-04      9.63E-05
```

Appendix B Stakeholder Consultation

CRC Overview

Mentimeter

What is your organisation's role regarding CRC?



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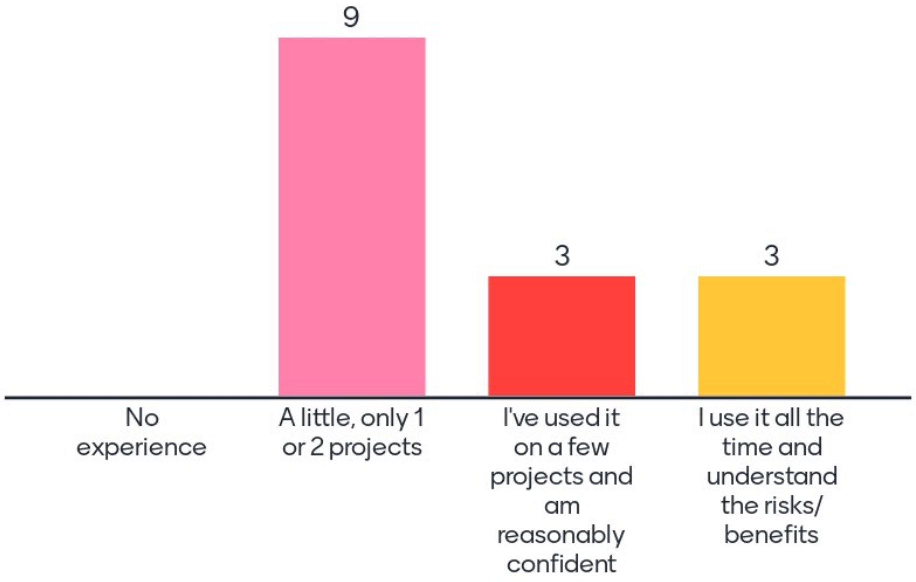
Mentimeter

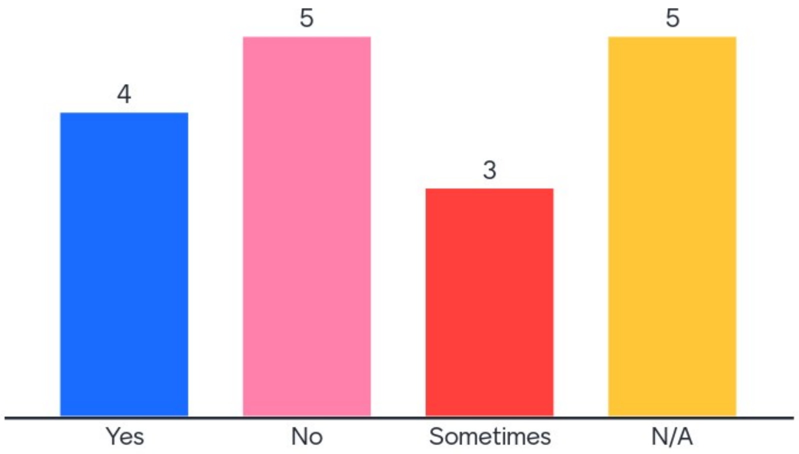
How would you rate your level of experience with CRC?



15

Mentimeter

Are you a Roads to Reuse accredited supplier or do you typically source material from RtR accredited suppliers?



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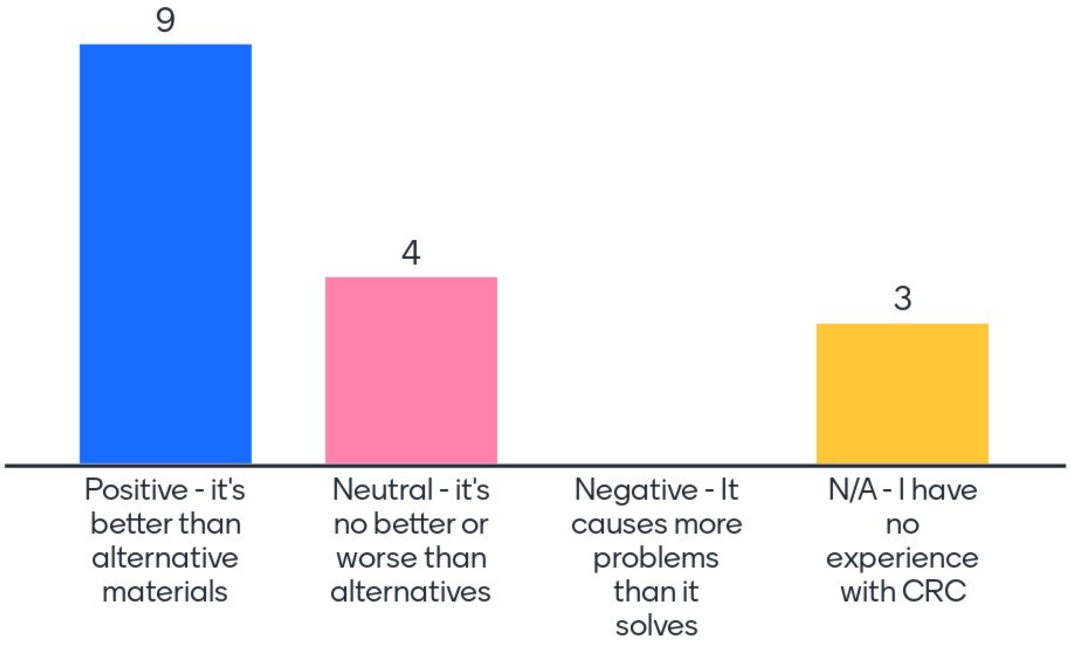
Perception of CRC

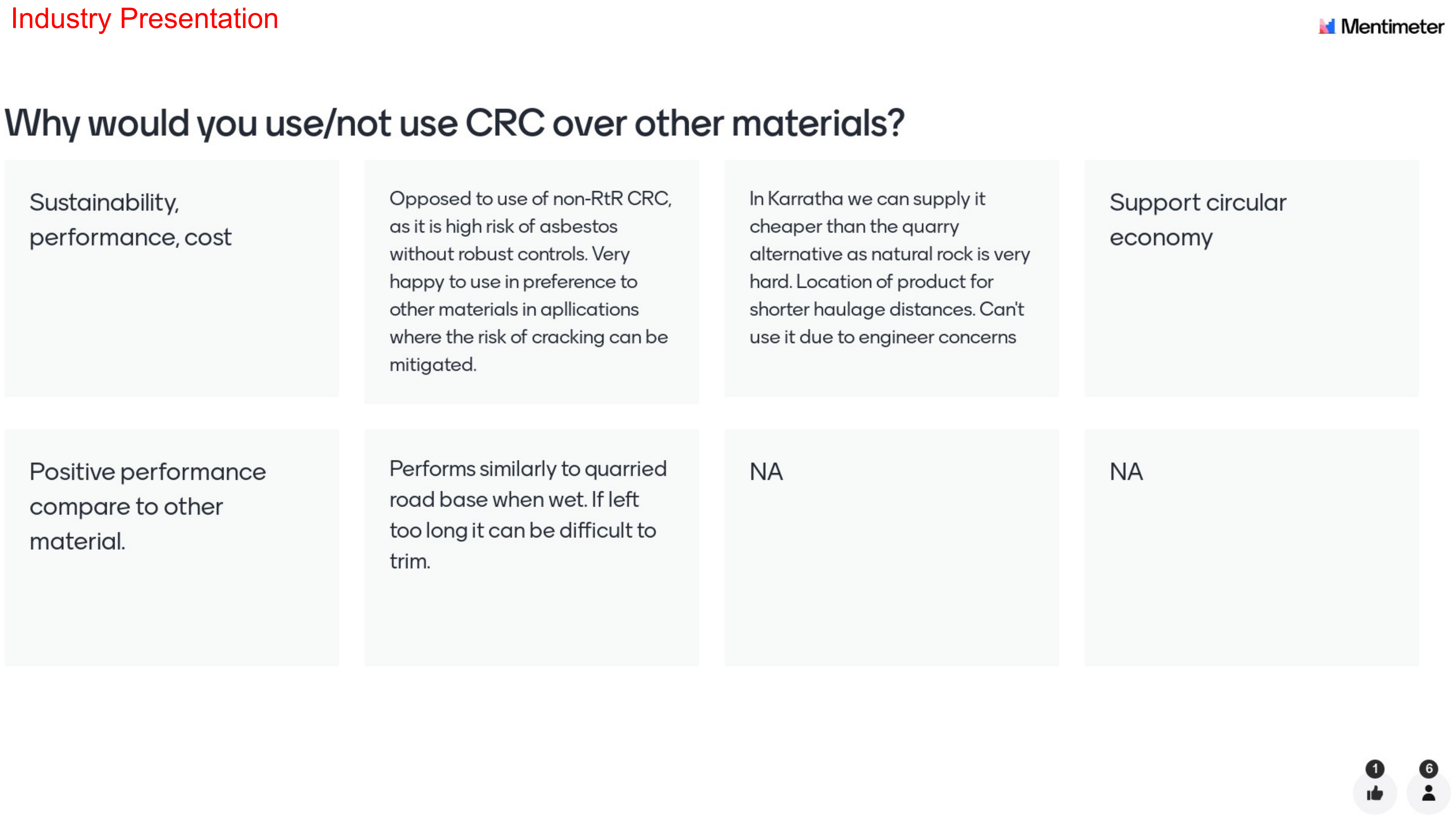
Mentimeter

What is your opinion of CRC?



2 16

Industry Presentation



Why would you use/not use CRC over other materials?

Sustainability, performance, cost

Opposed to use of non-RtR CRC, as it is high risk of asbestos without robust controls. Very happy to use in preference to other materials in apllications where the risk of cracking can be mitigated.

In Karratha we can supply it cheaper than the quarry alternative as natural rock is very hard. Location of product for shorter haulage distances. Can't use it due to engineer concerns

Support circular economy

Positive performance compare to other material.

Performs similarly to quarried road base when wet. If left too long it can be difficult to trim.

NA

NA

Industry Presentation

Mentimeter

What are some of your positive and negative experiences with CRC?

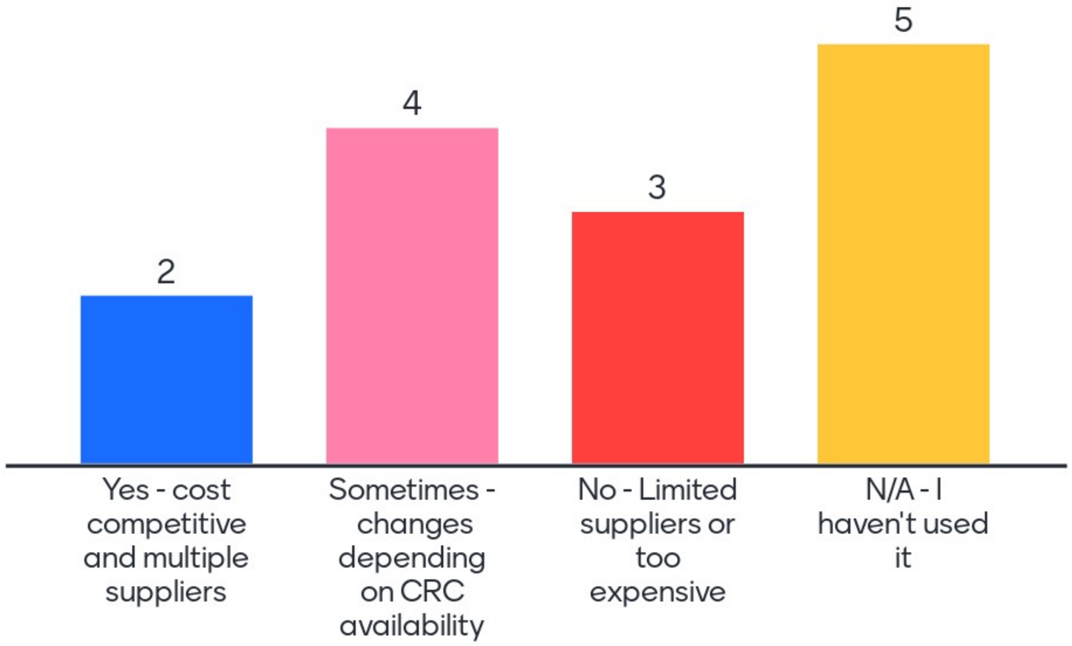
Significant base failures due to becoming bound. Need to recognise this in hesvy traffic conditions and design as cement stabilised

Positive: CRC produces an excellent tightly-bound surface finish for prime and seal.Tip: Essential to trim to level day after laying in, before it becomes unworkable.

2

Supply and Logistics

Is CRC typically easy to source?



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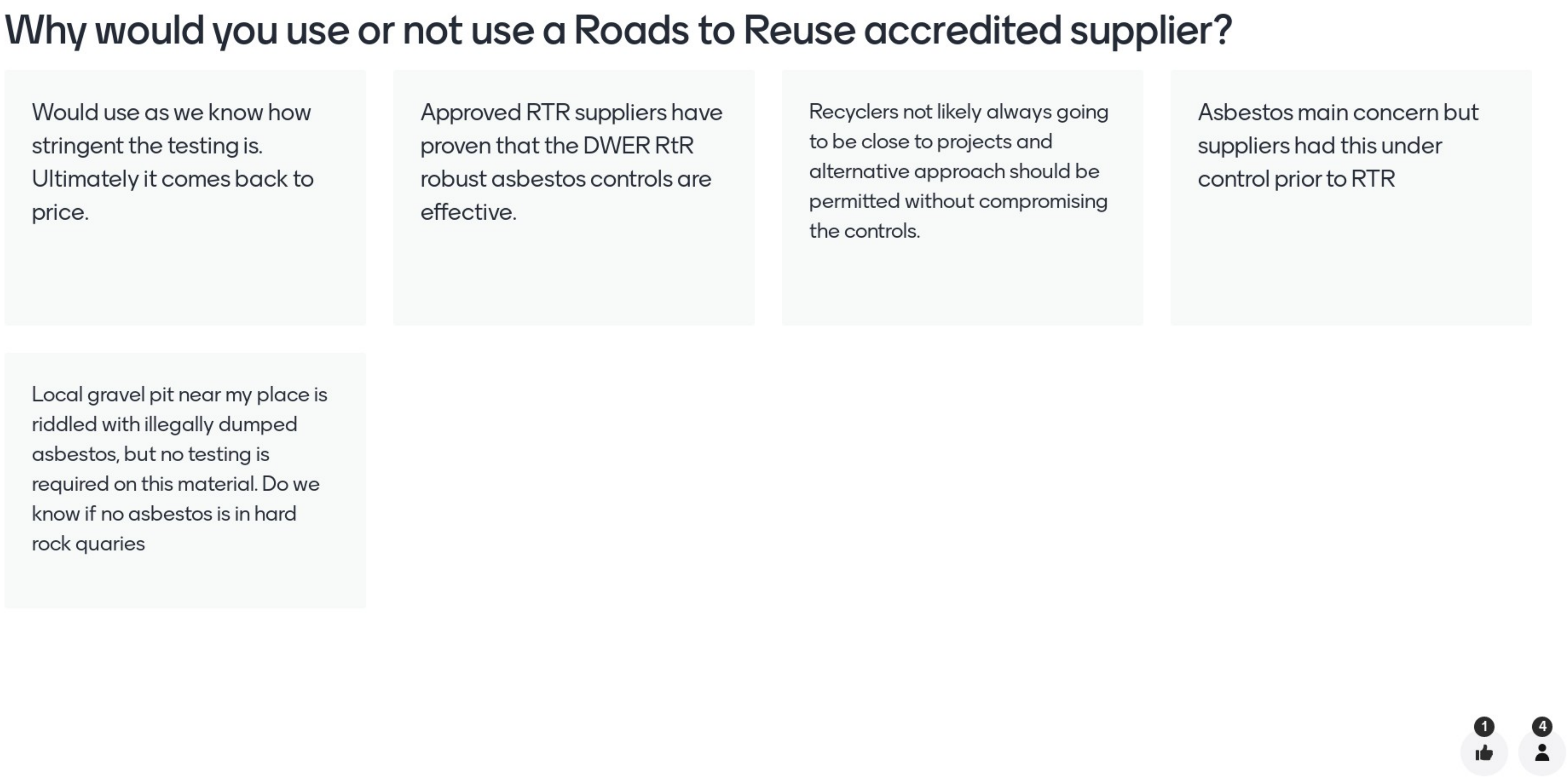
Industry Presentation



Why would you use or not use a Roads to Reuse accredited supplier?

Would use as we know how stringent the testing is. Ultimately it comes back to price.

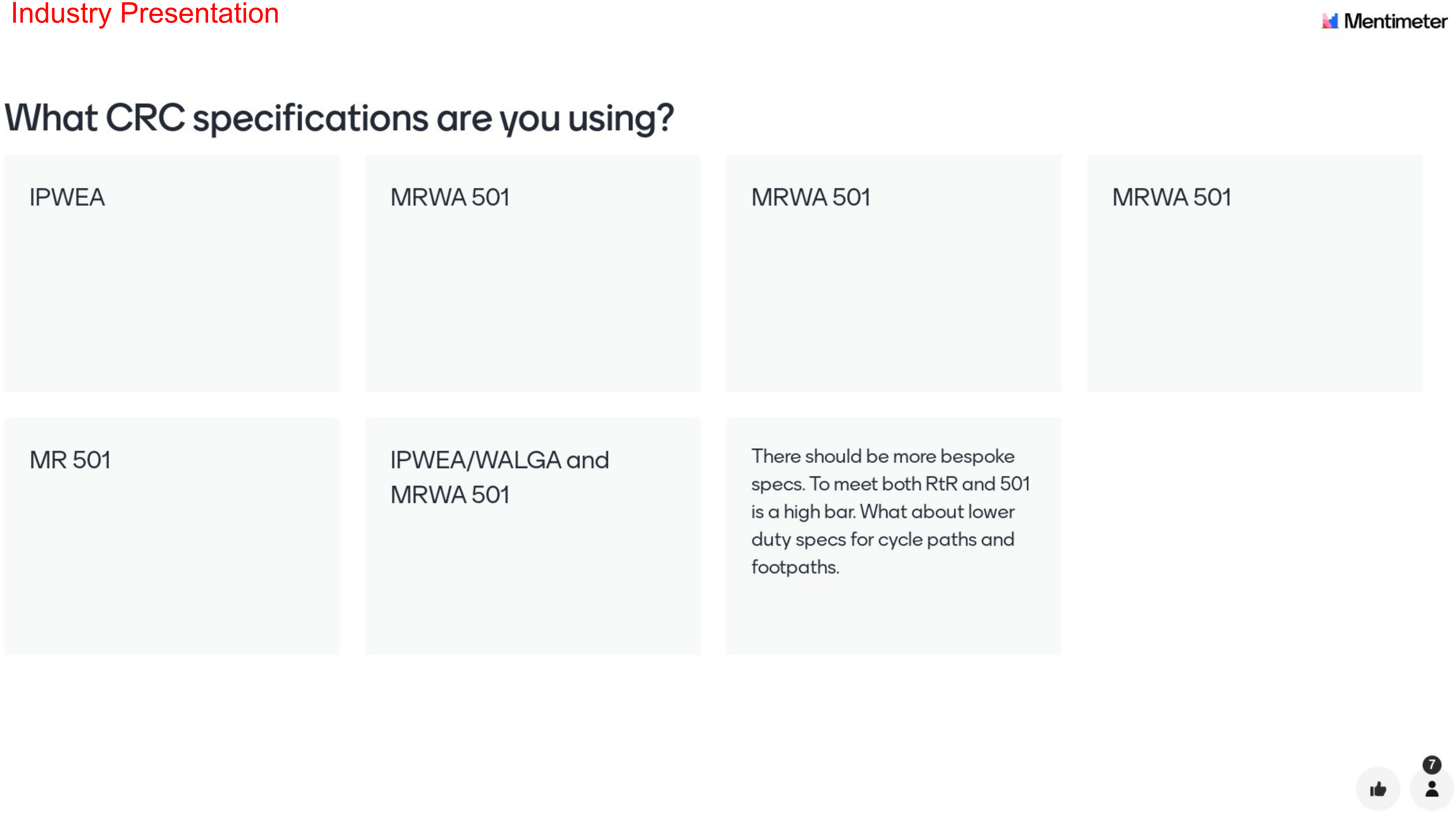
Approved RTR suppliers have proven that the DWER RtR robust asbestos controls are effective.

Recyclers not likely always going to be close to projects and alternative approach should be permitted without compromising the controls.

Asbestos main concern but suppliers had this under control prior to RTR

Local gravel pit near my place is riddled with illegally dumped asbestos, but no testing is required on this material. Do we know if no asbestos is in hard rock quaries

Industry Presentation



What CRC specifications are you using?

IPWEA

MRWA 501

MRWA 501

MRWA 501

MR 501

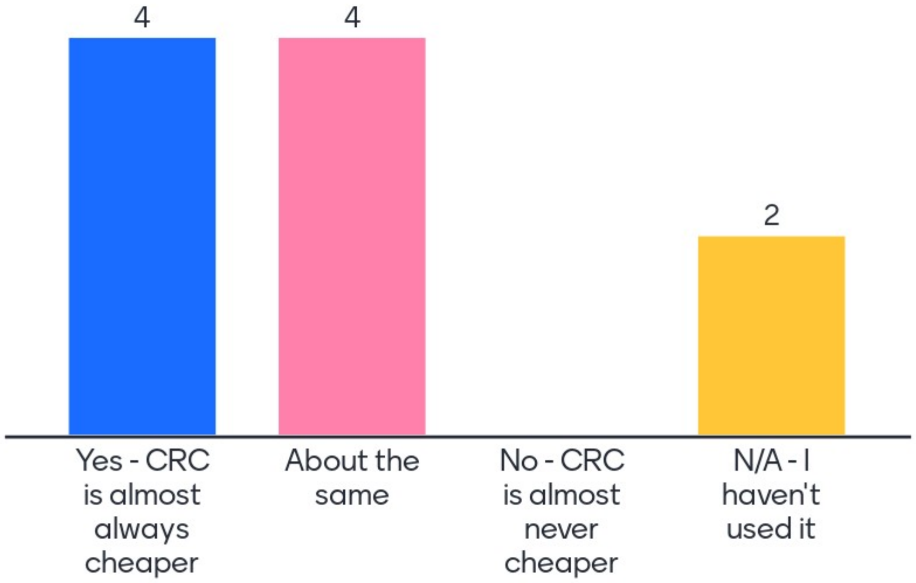
IPWEA/WALGA and MRWA 501

There should be more bespoke specs. To meet both RtR and 501 is a high bar. What about lower duty specs for cycle paths and footpaths.

Economics

Mentimeter

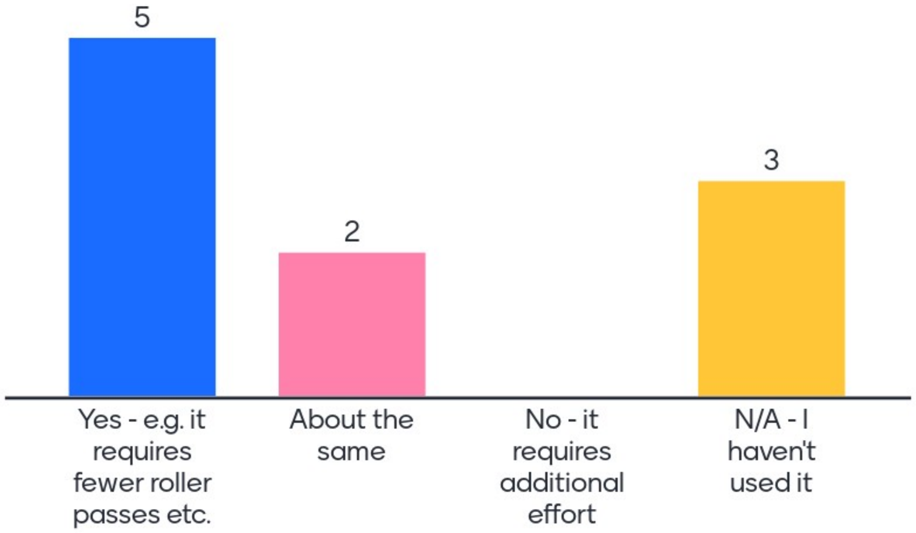
Is CRC cheaper than alternative pavement construction materials for your projects?



10

Mentimeter

Does the use of CRC reduce your overall pavement construction costs?

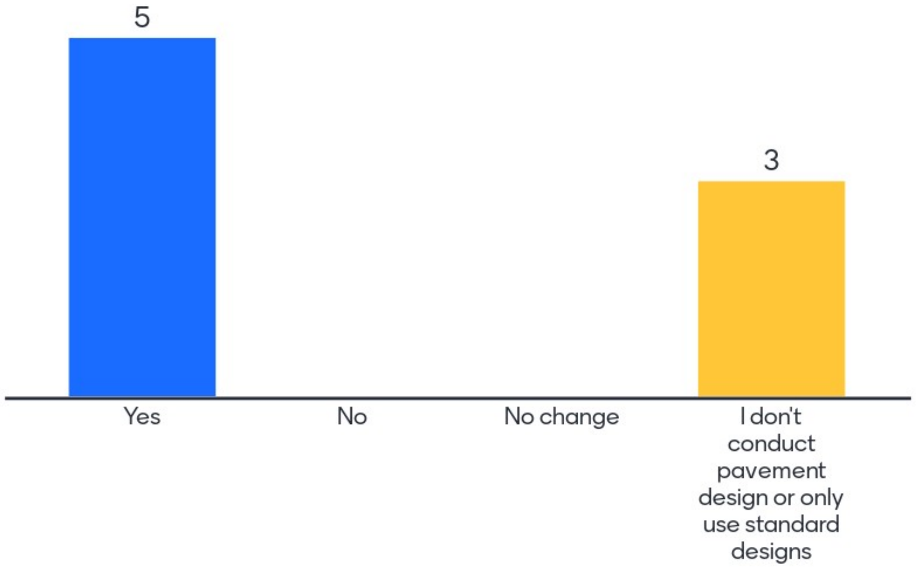


10

Mentimeter

Design and Construction

Does the use of CRC change your approach to pavement design?



If your approach to pavement design changes, how?

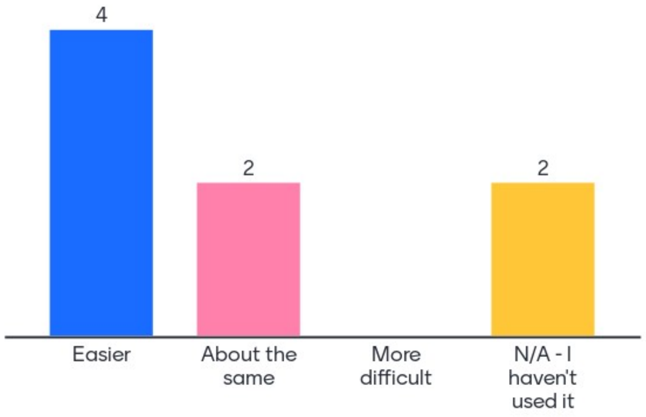
Yes, bound, low modulus

MRWA characterises the material as lightly bound, somwhat stiffer than "modified", but less stiff than deliberately boubd heavy cement stabilised.

2

Mentimeter

On average, is CRC easier or more difficult to work (place, moisture condition, compact, trim) compared to other pavement construction materials?



8

Mentimeter

What issues have you experienced associated with CONSTRUCTION using CRC?

Little bit more water thsn CRB

Being delayed between placement and compaction and final trimming. Once it starts to set, it tears as you try to trim it, or the blade just skips off.

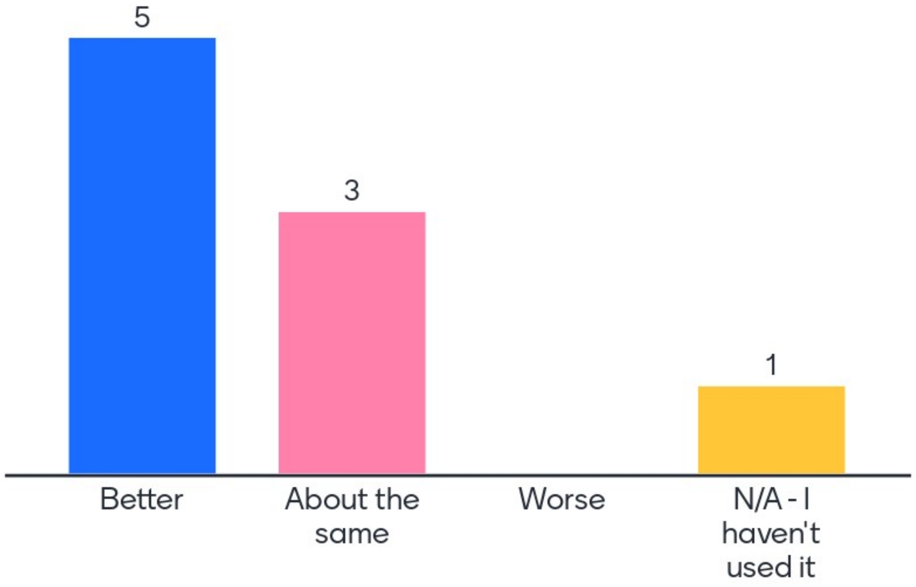
More variable, more testing required.

3

Performance

Mentimeter

How do CRC pavements perform compared with other materials?



9

Industry Presentation

Mentimeter

What performance issues haveyou experienced with CRC pavements?

None

Fatigue due to design method, transverse and block cracking

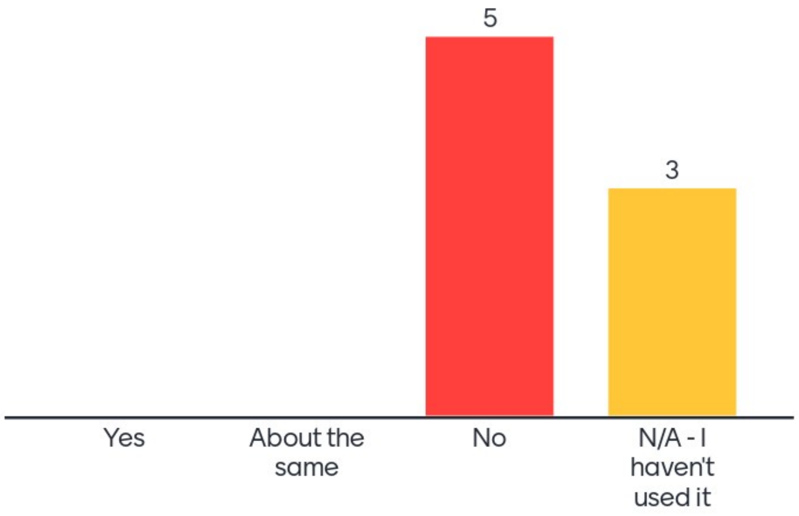
Lower risk of potholes, deformation, rutting.Low risk of popping.Risk 9f shrinkage cracking.

None

Need more bespoke specs for low-duty and low risk applications.

5

Do CRC pavements have increased defects (e.g. requiring contractor repair during defects liability period)?



8

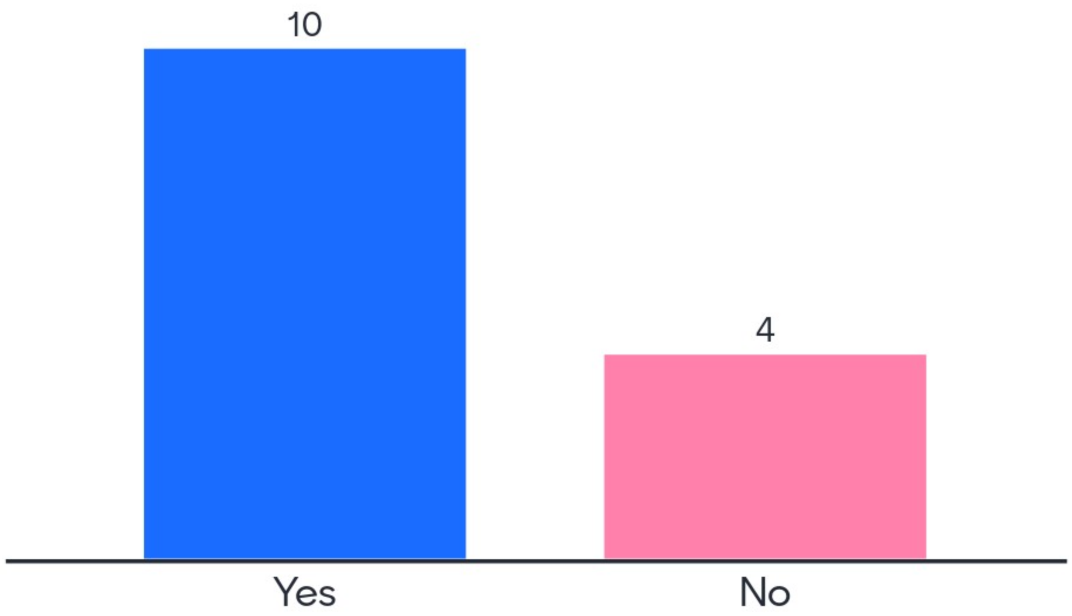
Mentimeter

CRC Overview

1

Mentimeter

Has your organisation used CRC?



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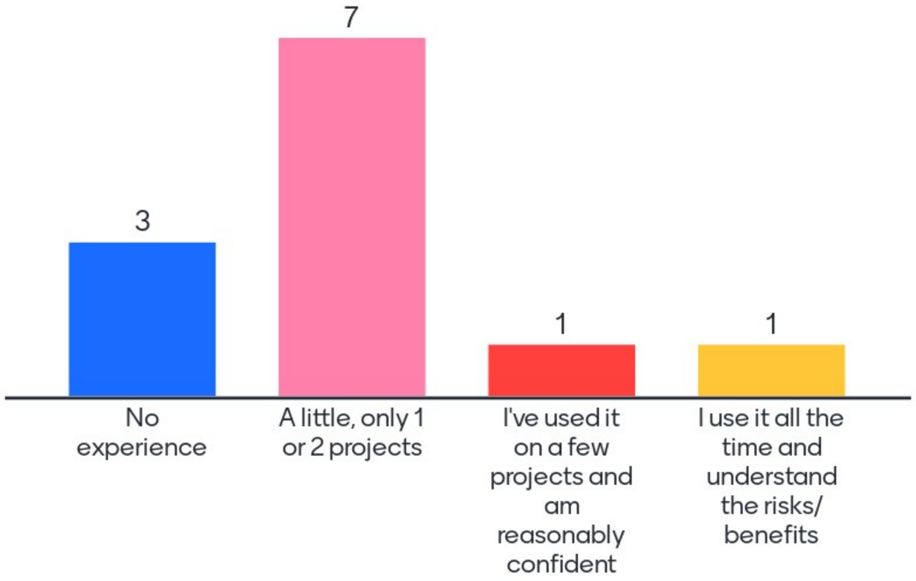
👤 14

Practitioners Presentation

Mentimeter

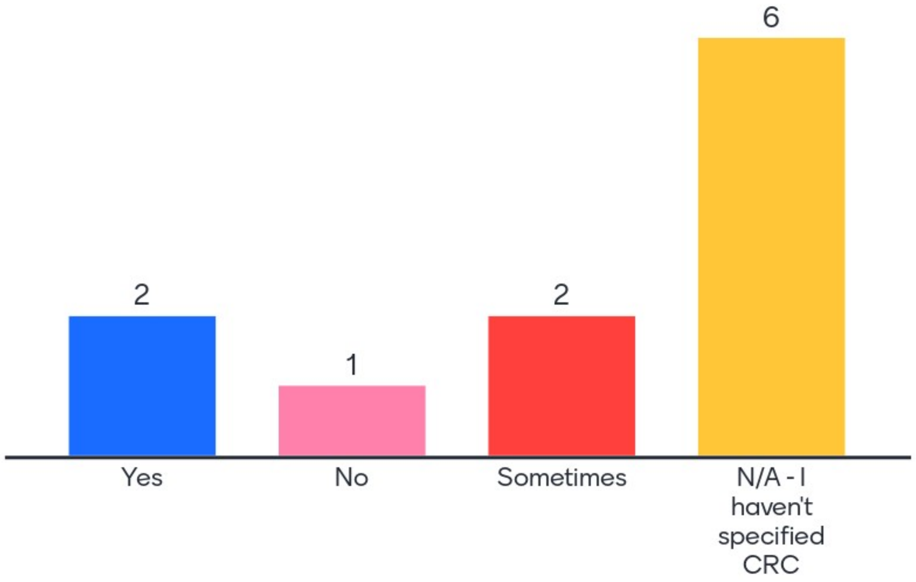
How would you rate your level of experience with CRC?



12

Mentimeter

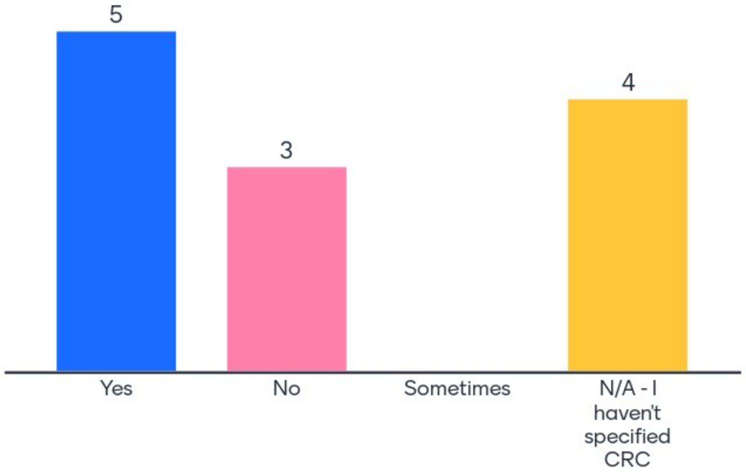
Do you typically use a Roads to Reuse accredited supplier for CRC?



11

Mentimeter

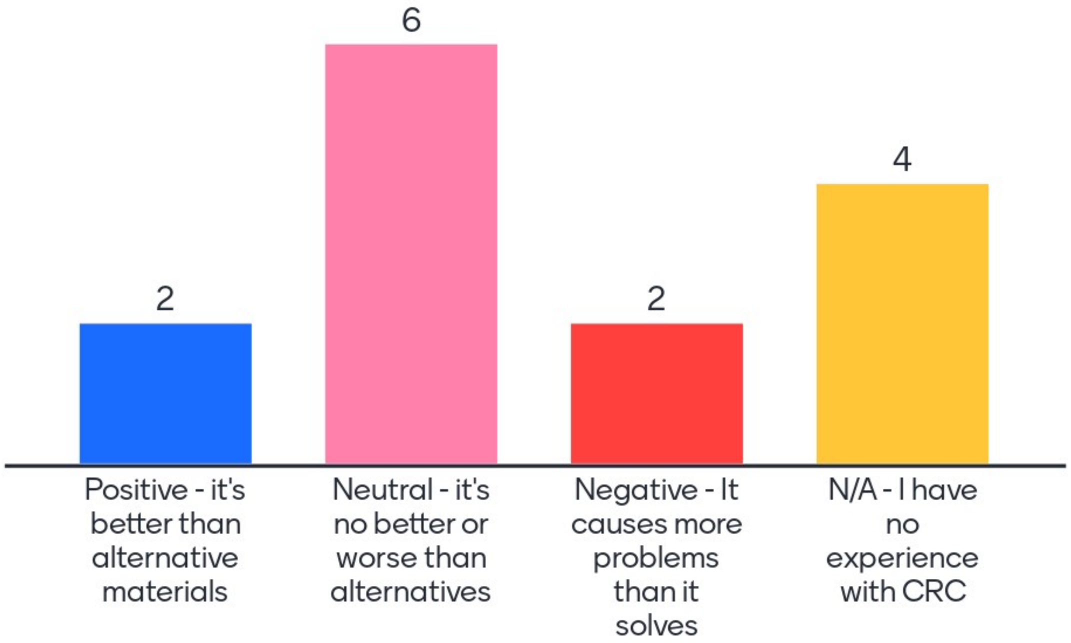
Do you typically use the IPWEA/WALGA "Specification for the supply of recycled road base" for CRC



12

Perception of CRC

What is your opinion of CRC?



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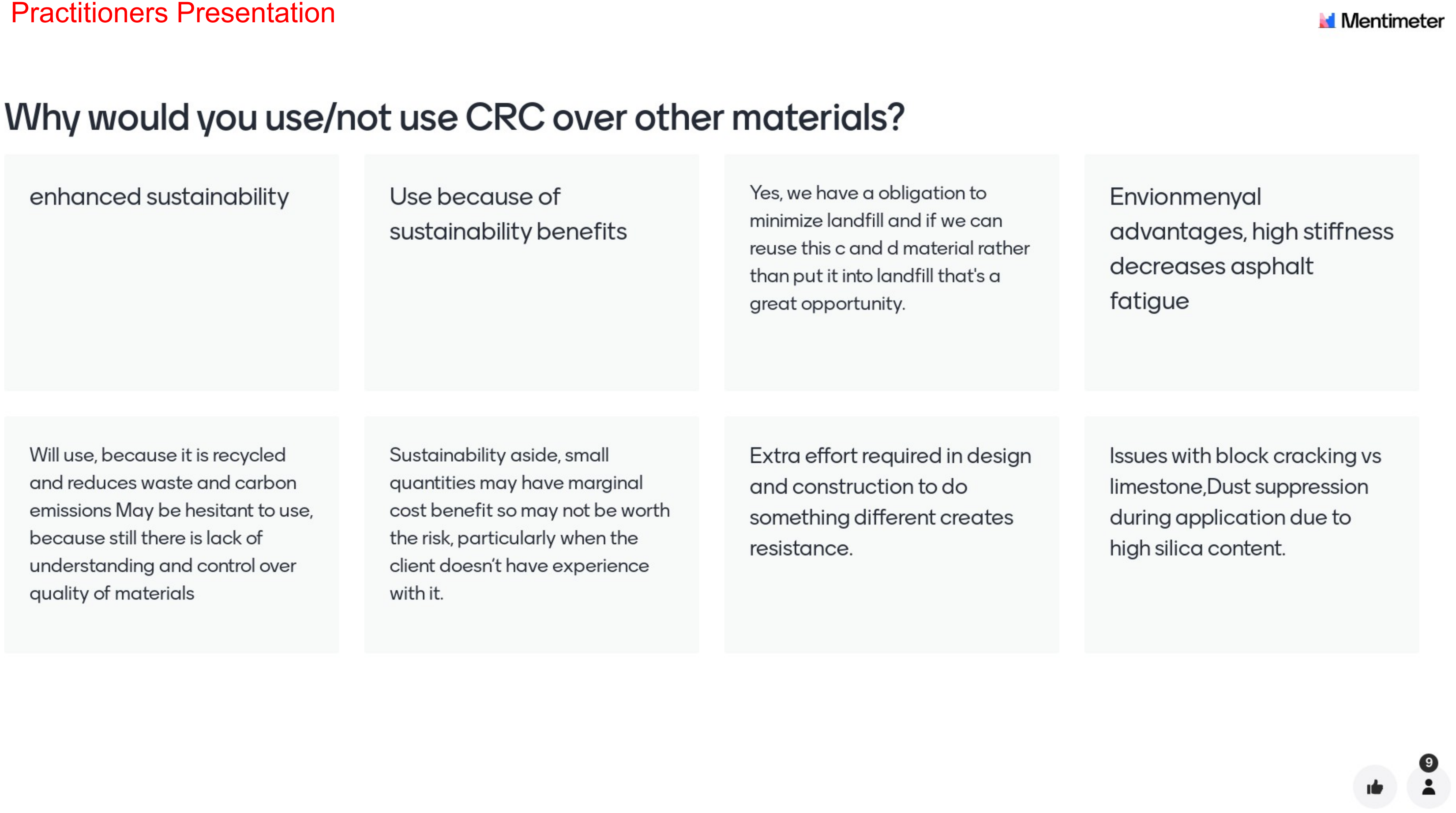
Practitioners Presentation



Why would you use/not use CRC over other materials?

enhanced sustainability

Use because of sustainability benefits

Yes, we have a obligation to minimize landfill and if we can reuse this c and d material rather than put it into landfill that's a great opportunity.

Envionmenyal advantages, high stiffness decreases asphalt fatigue

Will use, because it is recycled and reduces waste and carbon emissions May be hesitant to use, because still there is lack of understanding and control over quality of materials

Sustainability aside, small quantities may have marginal cost benefit so may not be worth the risk, particularly when the client doesn't have experience with it.

Extra effort required in design and construction to do something different creates resistance.

Issues with block cracking vs limestone,Dust suppression during application due to high silica content.

Practitioners Presentation

Mentimeter

Why would you use/not use CRC over other materials?

Availability in regions for regional projects.

Sustainability - reduce land fill.

Sustainability aspects , to encourage to use Not to use , performance and life cycle of assets , quality of CRC

Dust Suppression due to high silica content

design ambiguity from high variability of material

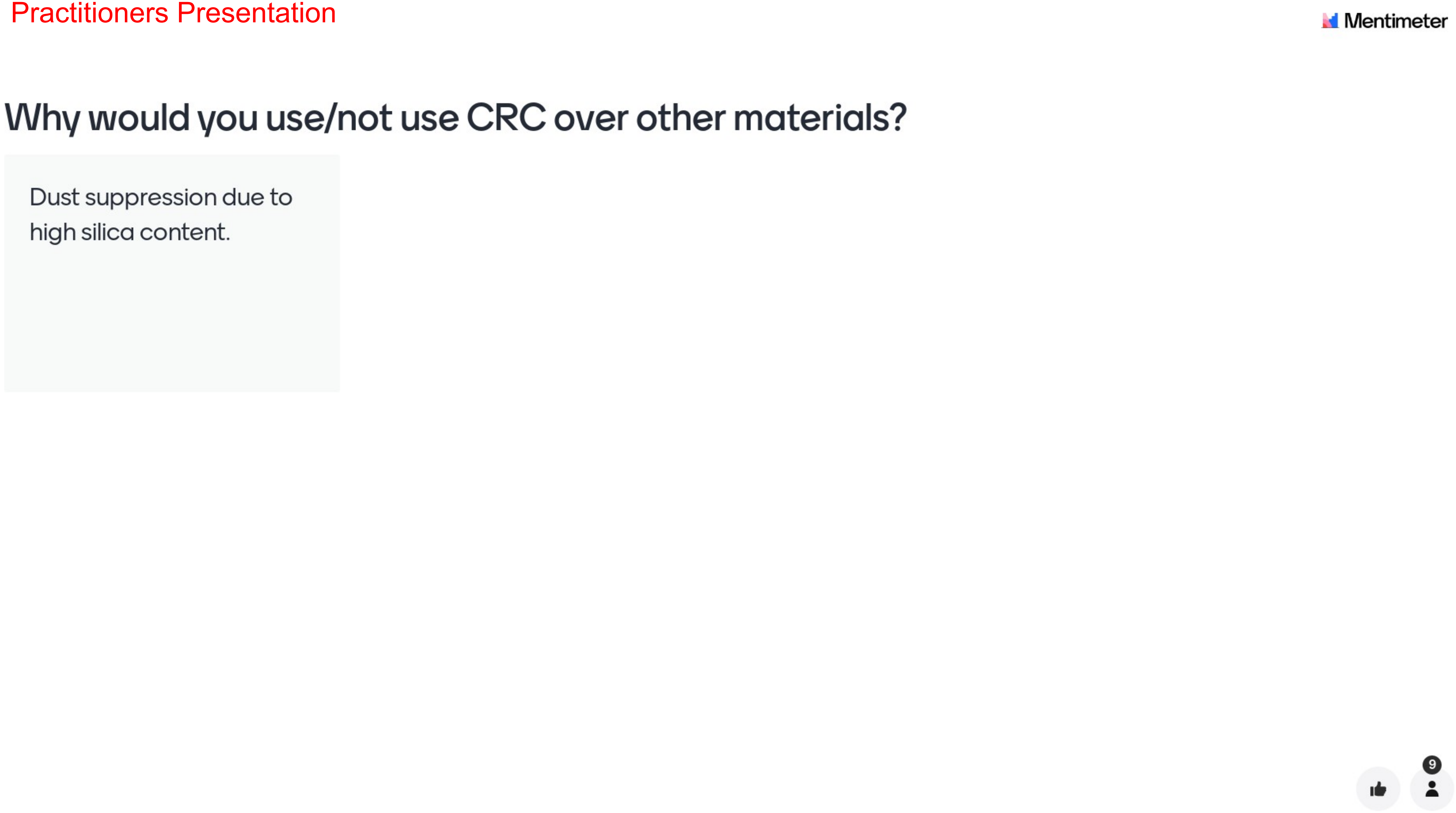
Positive: used for sub base and kerb base... very strong material and withstand heavy loads

design ambiguity from high variability of material

Negative: block cracking, quality of the material

9

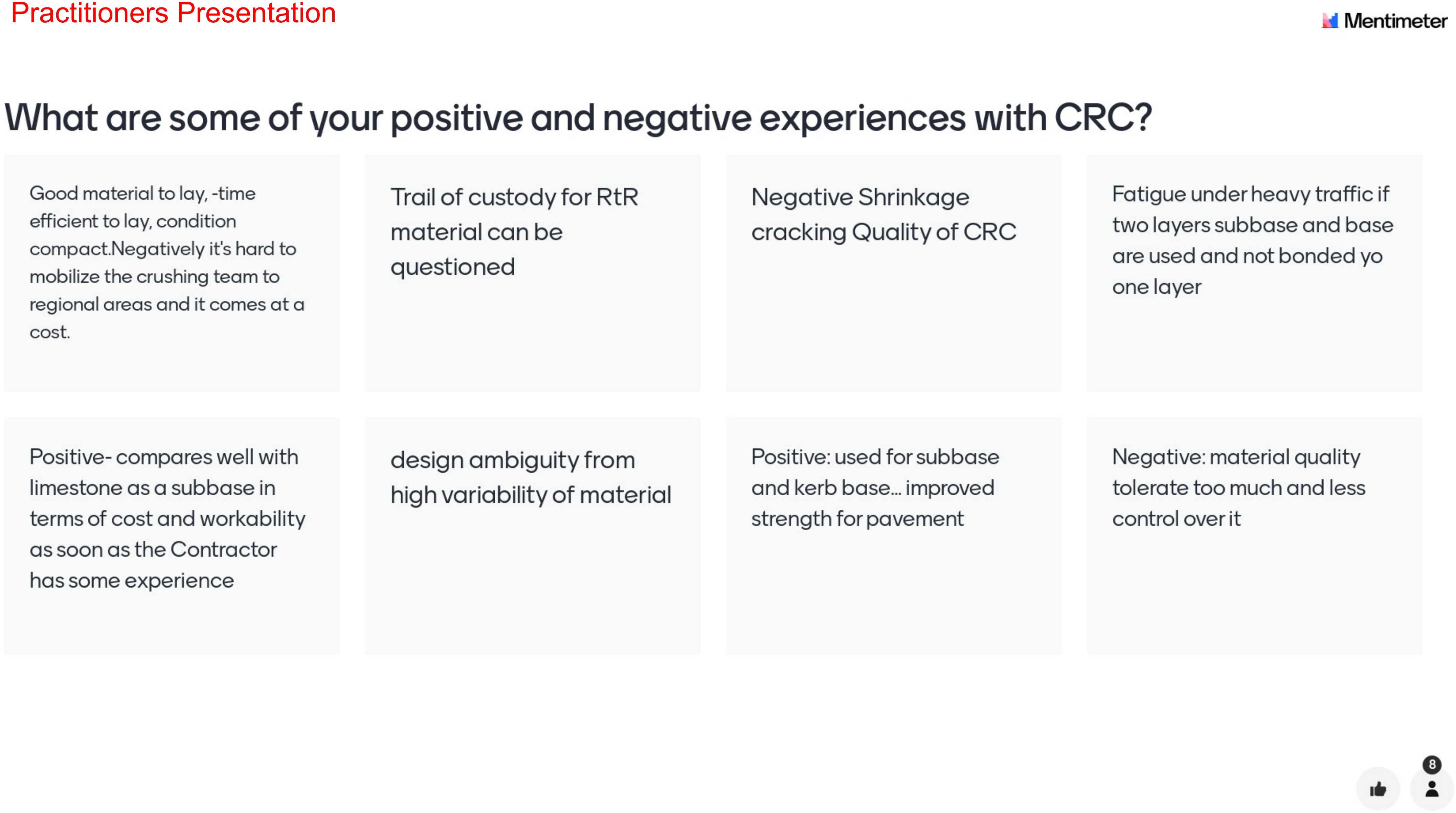
Practitioners Presentation



Why would you use/not use CRC over other materials?

Dust suppression due to high silica content.

Practitioners Presentation



What are some of your positive and negative experiences with CRC?

Good material to lay, -time efficient to lay, condition compact.Negatively it's hard to mobilize the crushing team to regional areas and it comes at a cost.

Trail of custody for RtR material can be questioned

Negative Shrinkage cracking Quality of CRC

Fatigue under heavy traffic if two layers subbase and base are used and not bonded yo one layer

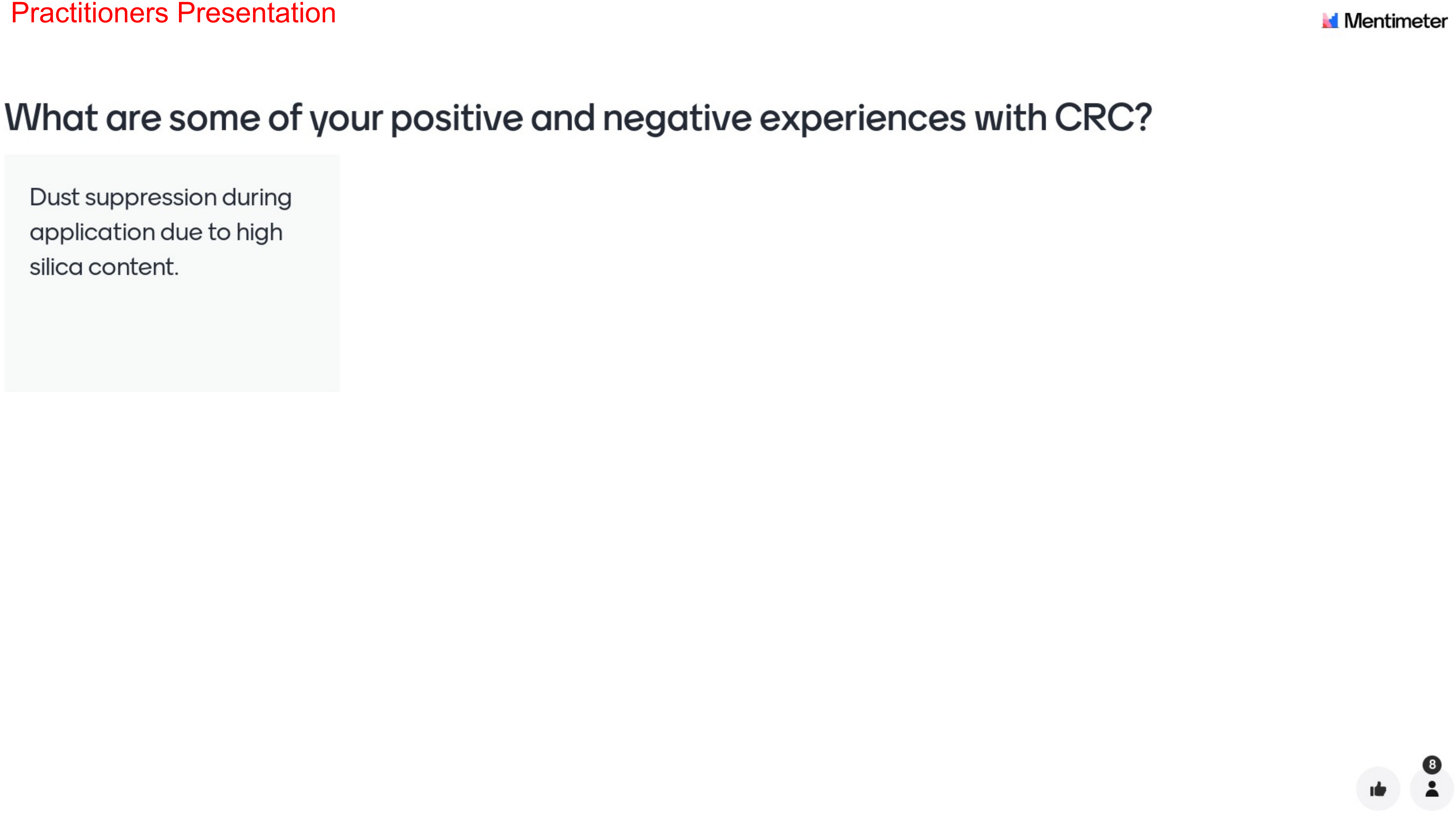
Positive- compares well with limestone as a subbase in terms of cost and workability as soon as the Contractor has some experience

design ambiguity from high variability of material

Positive: used for subbase and kerb base... improved strength for pavement

Negative: material quality tolerate too much and less control over it

Practitioners Presentation



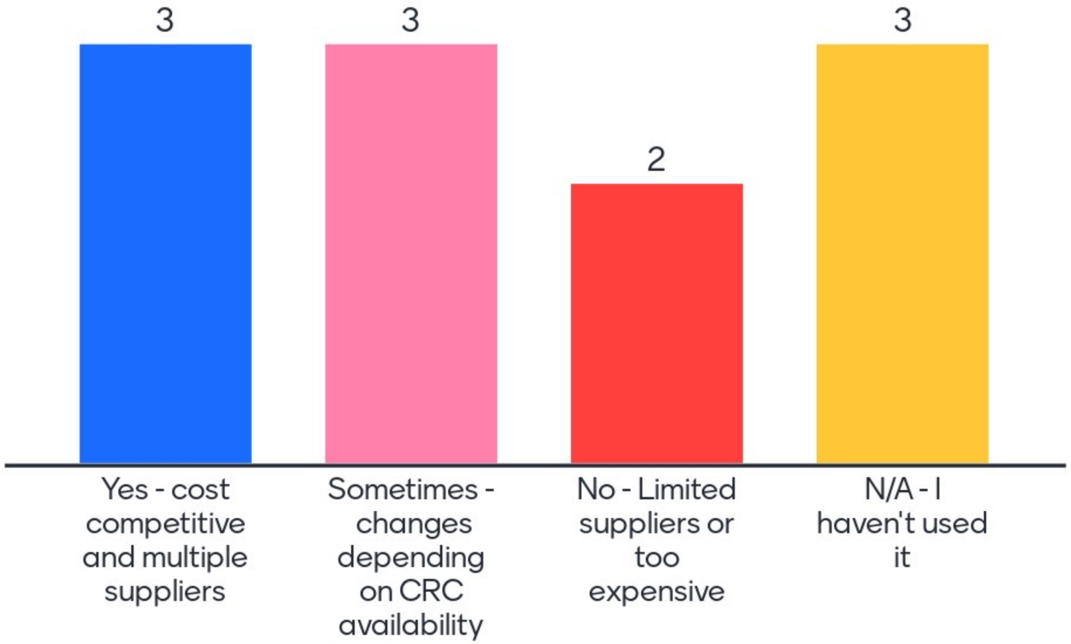
What are some of your positive and negative experiences with CRC?

Dust suppression during application due to high silica content.

Supply and Logistics

Mentimeter

Is CRC typically easy to source?



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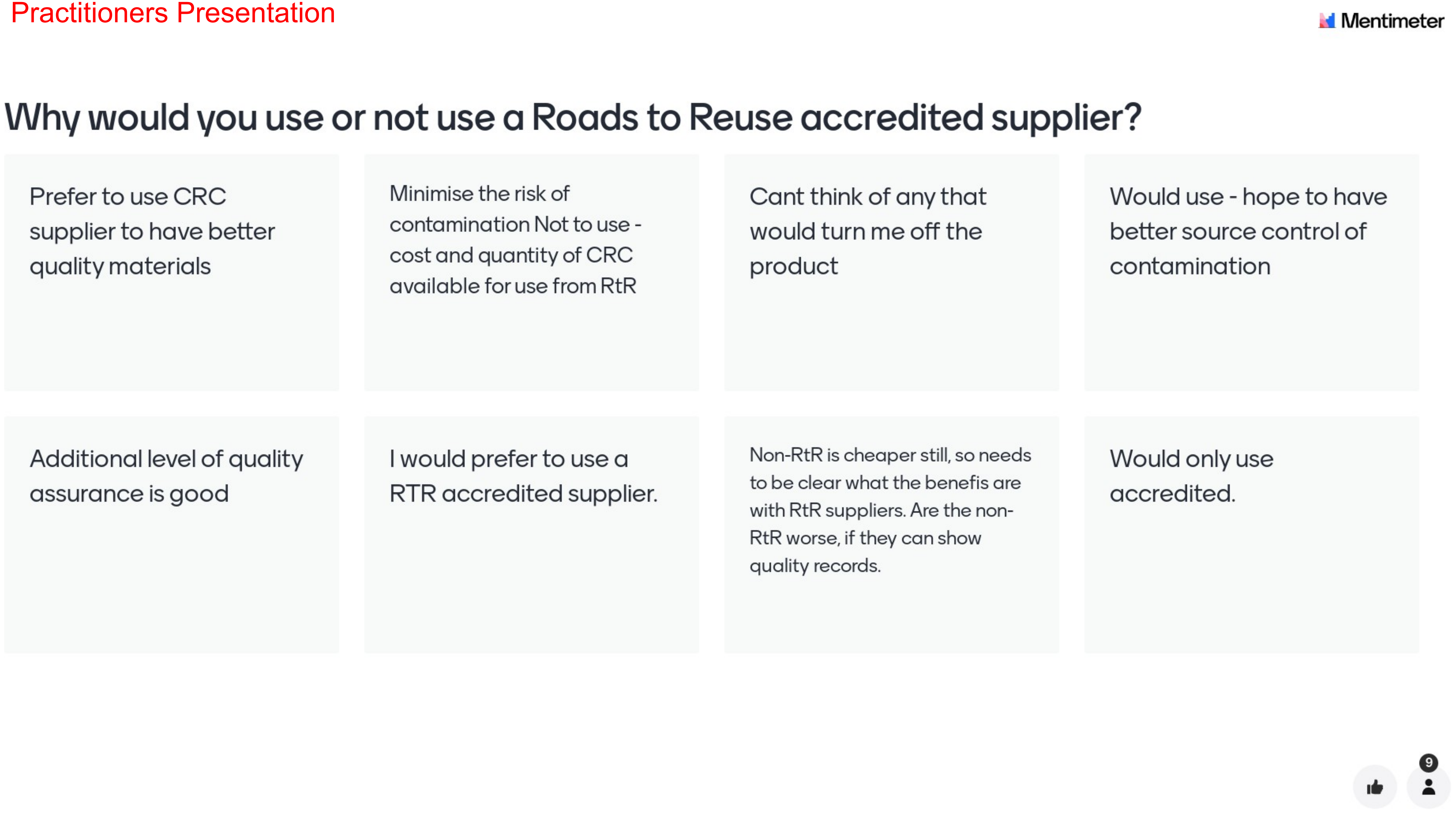
Practitioners Presentation



Why would you use or not use a Roads to Reuse accredited supplier?

- Prefer to use CRC supplier to have better quality materials
- Minimise the risk of contamination Not to use - cost and quantity of CRC available for use from RtR
- Cant think of any that would turn me off the product
- Would use - hope to have better source control of contamination
- Additional level of quality assurance is good
- I would prefer to use a RTR accredited supplier.
- Non-RtR is cheaper still, so needs to be clear what the benefis are with RtR suppliers. Are the non-RtR worse, if they can show quality records.
- Would only use accredited.

Practitioners Presentation

Mentimeter

Why would you use or not use a Roads to Reuse accredited supplier?

Would use once more QA is achieved

IPWEA WALGA

9

What CRC specifications are you using?

Ipwea

IPWEA/WALGA

PTA spec and IPWEA spec

PTA

IPWEA/WALGA

we crushed the material and then had it tested to see what we could use it for. the desire was for roadbase but it just fell short on the grading

MRWA 501 and PTA

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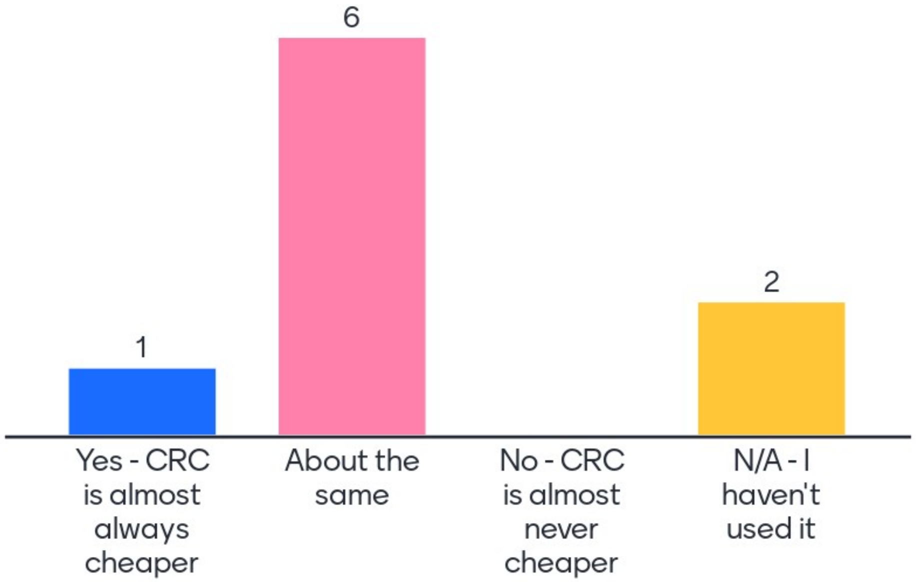
Economics

Is CRC cheaper than alternative pavement construction materials for your projects?



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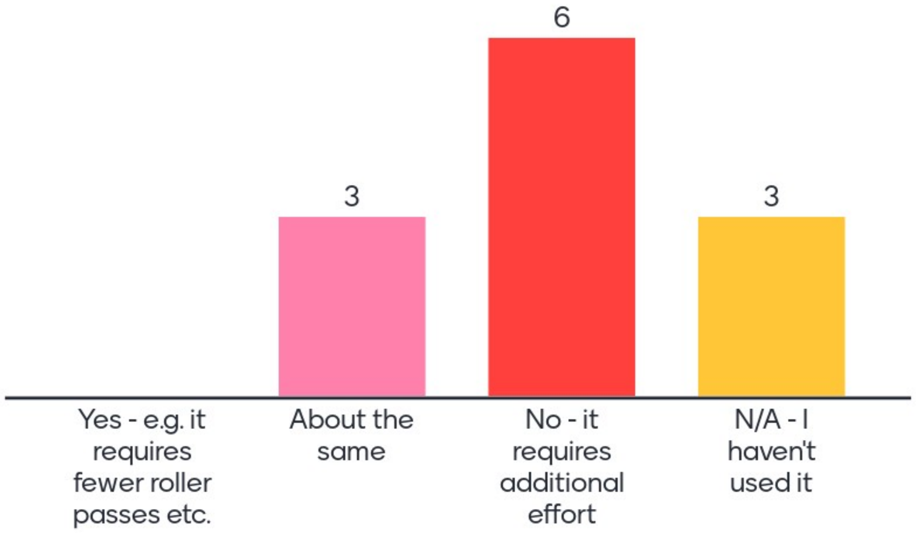
Does the use of CRC reduce your overall project cost?



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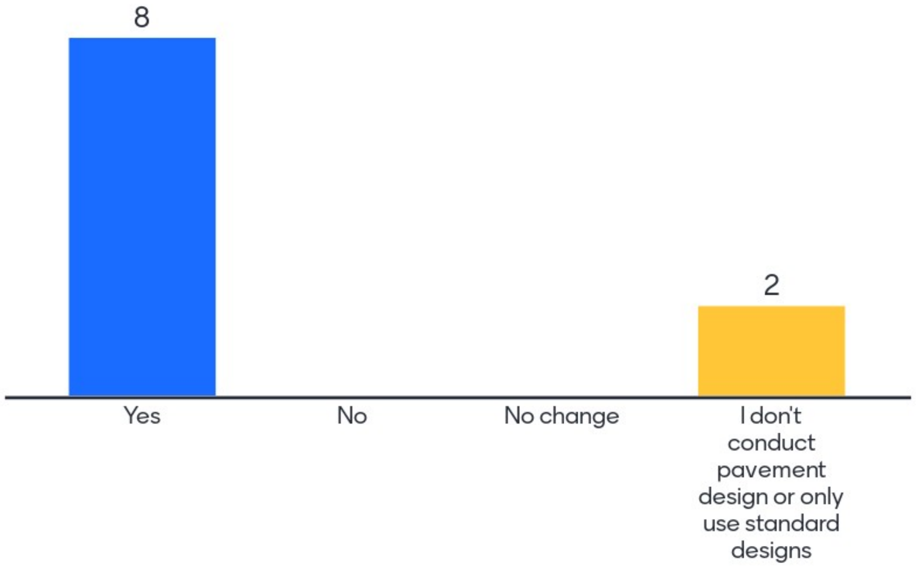
Design and Construction

Mentimeter

Does the use of CRC change your approach to pavement design?



10

Mentimeter

If your approach to pavement design changes, how?

Design as bound

I think this is where more technical guidance is needed to facilitate greater use of the material

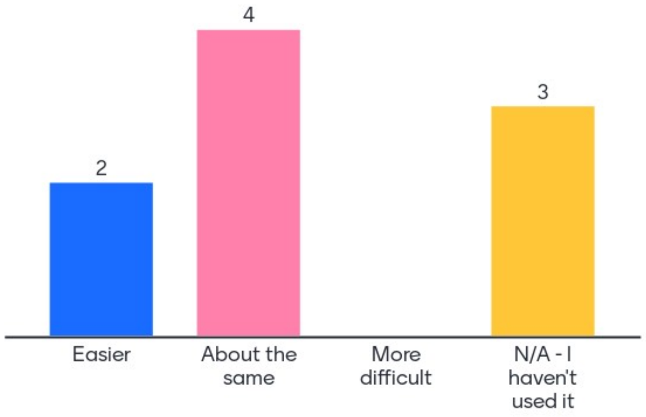
Yes design as a bound .

3

Practitioners Presentation

Mentimeter

On average, is CRC easier or more difficult to work (place, moisture condition, compact, trim) compared to other pavement construction materials?



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What issues have you experienced associated with CONSTRUCTION using CRC?

None

Quality control and testing

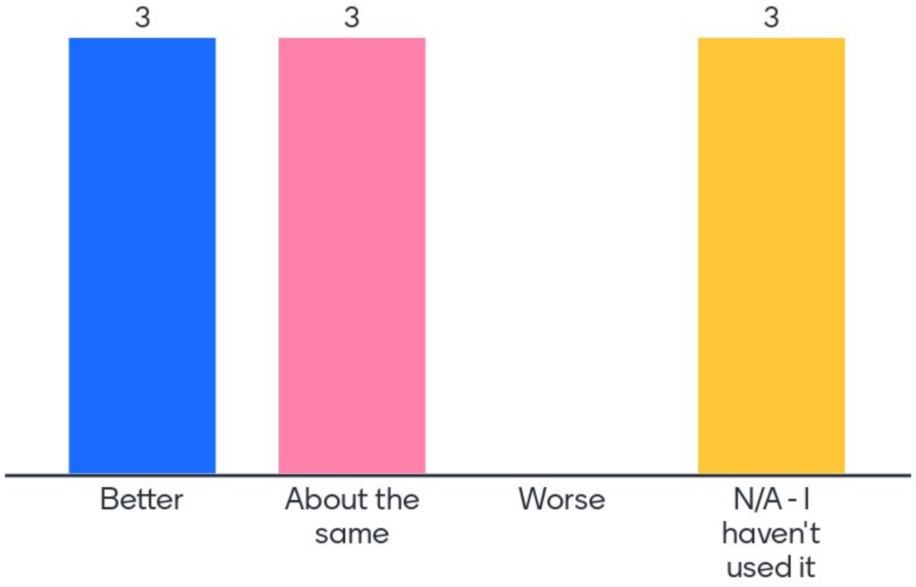
2

Mentimeter

Performance

Mentimeter

How do CRC pavements perform compared with other materials?



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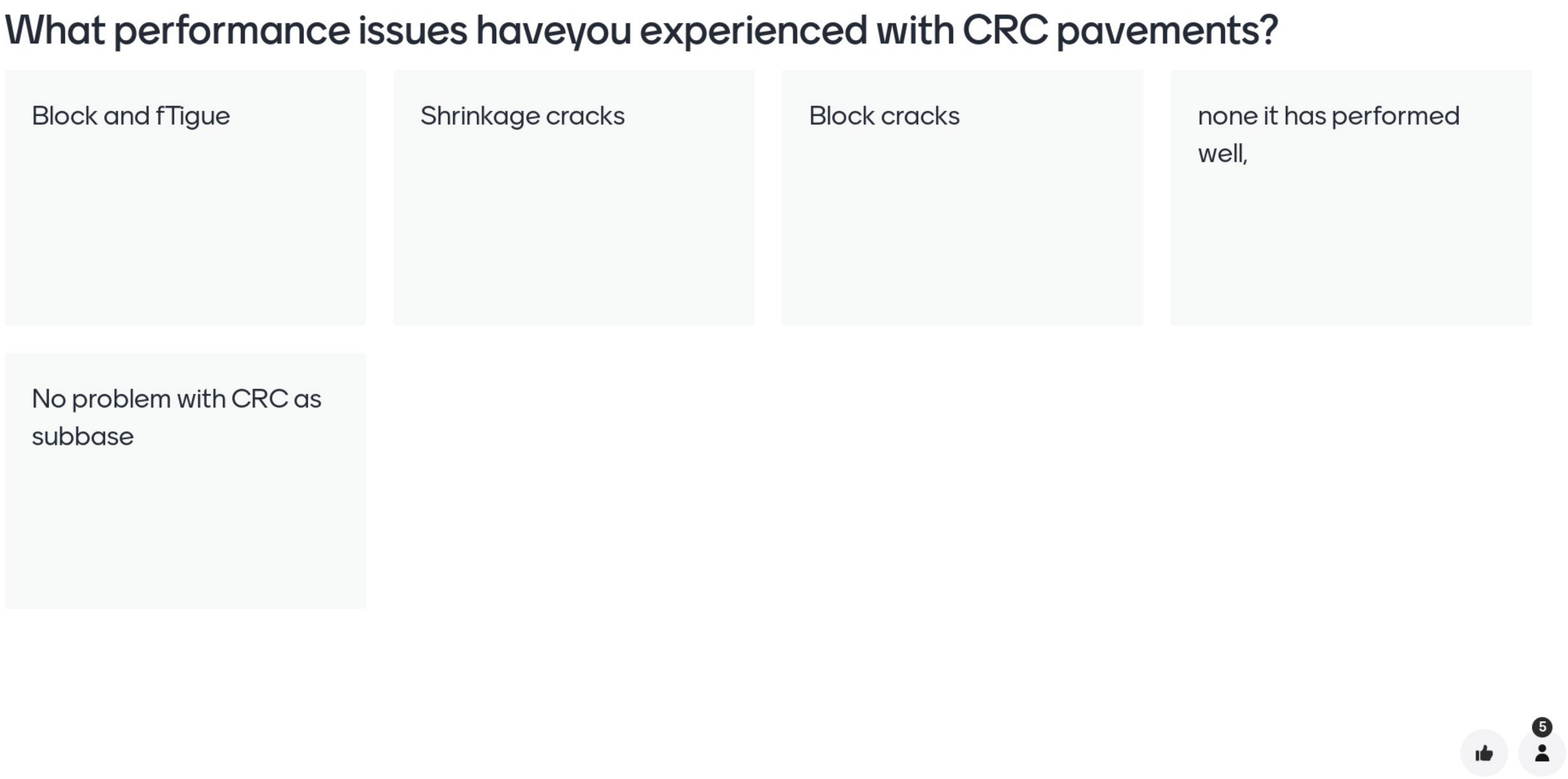
Practitioners Presentation



What performance issues haveyou experienced with CRC pavements?

Block and fTigue

Shrinkage cracks

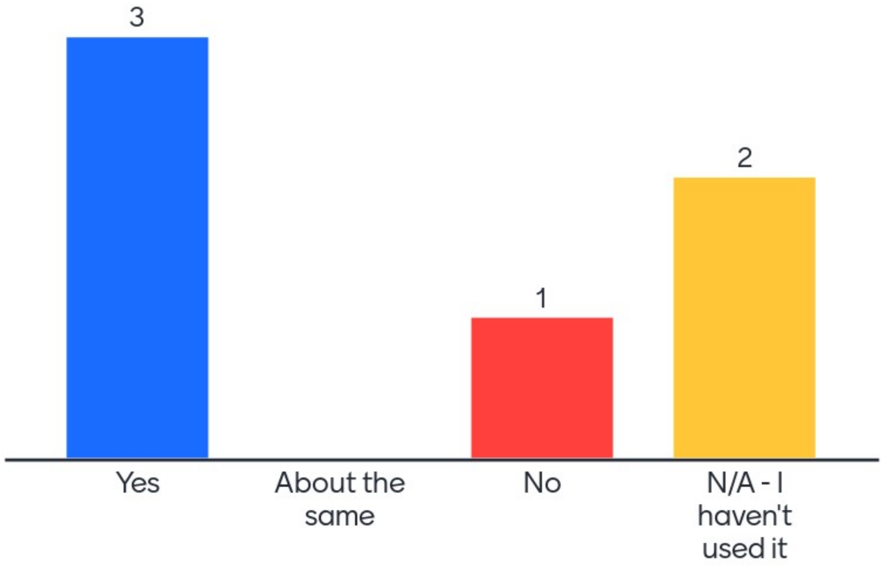
Block cracks

none it has performed well,

No problem with CRC as subbase

Practitioners Presentation

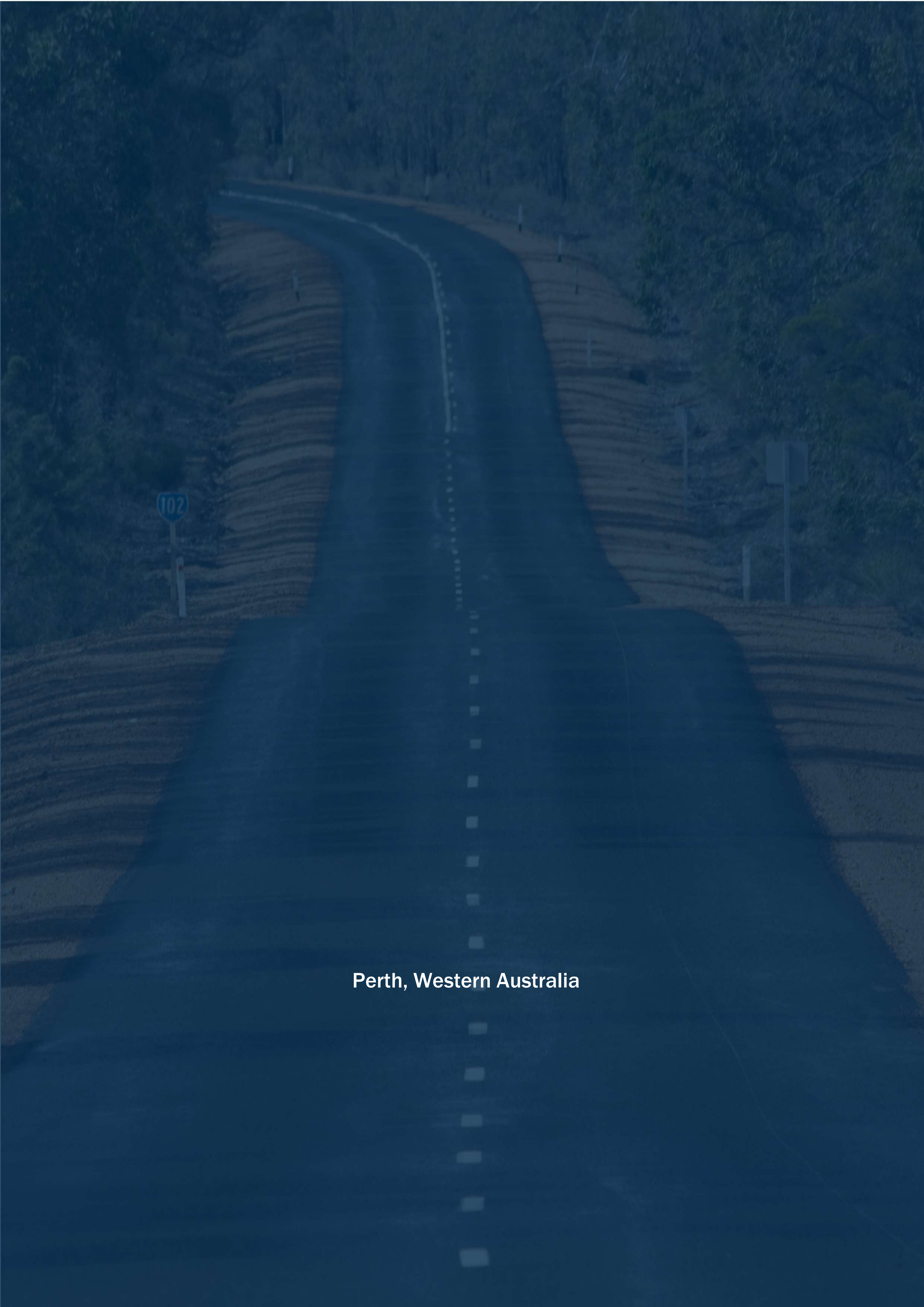
Do CRC pavements require increased maintenance?



How does the maintenance of CRC pavements differ from other materials?

- Crack sealing
- Crack sealing
- Potentially closer monitoring required

3



Perth, Western Australia