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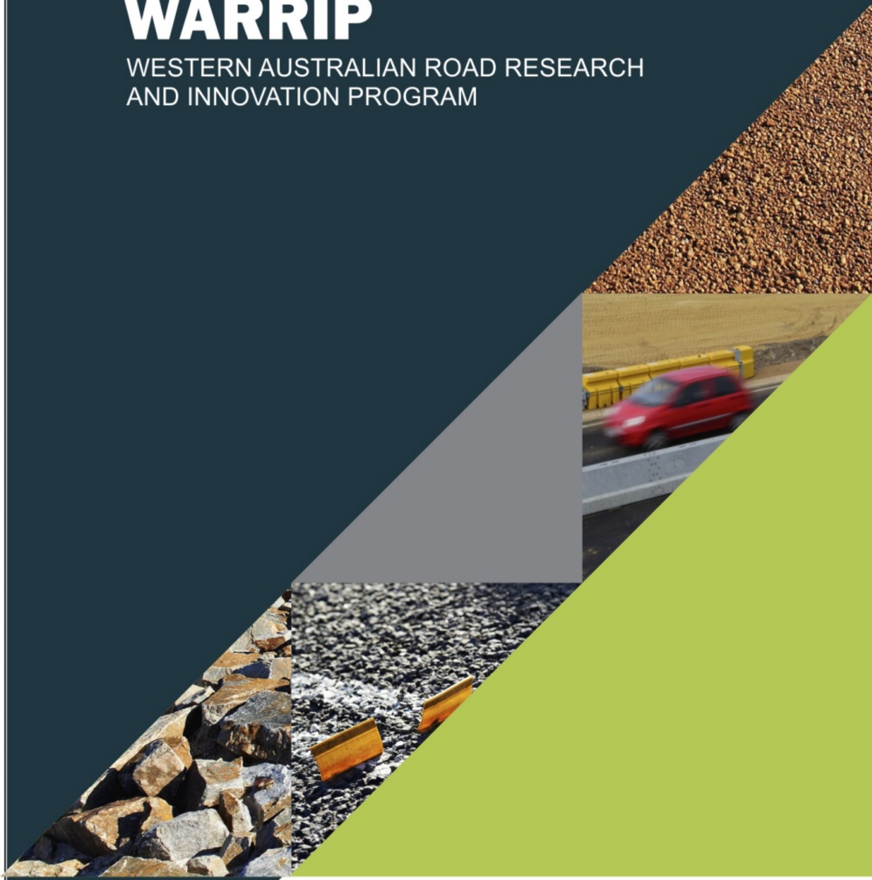

WARRIP 2021-002
Effect of moisture on asphalt pavement performance

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Acknowledgement of Country

I begin today by acknowledging the Traditional Custodians of the land on which we meet today and pay my respects to their Elders past and present. I extend that respect to Aboriginal and Torres Strait Islander peoples here today.

Housekeeping

- Restrooms
- Emergencies
- Phones
- Refreshments
- Questions
- Engagement

About WARRIP

WARRIP
WESTERN AUSTRALIAN
ROAD RESEARCH &
INNOVATION PROGRAM

The Western Australian Road Research and Innovation Program is a joint initiative between Main Roads Western Australia and the Australian Road Research Board.

The program 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.

Today's presenter

Atteeq Ur-Rehman
ARRB (NTRO)

Principal Professional Leader
ARRB Project Leader

Topic	Presenter
Factors affecting stripping	Atteeq
Comparison of practices with other Australian road agencies	Atteeq
Stripping occurrences on MRWA projects	Atteeq/Les
International road agencies practices	Atteeq
Analysis of Gateway field trials	Atteeq
Key findings and recommendations	Atteeq
Q+A	Atteeq & Les

The Project - Overview

- Objective: Improved guidance to reduce moisture induced failures in asphalt pavements in WA.

- Project Components:
  - Literature review
  - Virtual Workshop
  - Data analysis and linkages to Main Roads practice
  - Reporting

Scope of Literature Review

Asphalt Stripping Research Findings

- Stripping mechanisms
- Moisture-induced damage
- Critical design factors
- Aggregate mineralogy
- Testing, road design and construction considerations

Comparison of Australian SRAs Practices

- AIC, DGA, SMA, OGA, CRA, EME2
- Volumetric requirements
- Performance requirements
- Field compaction
- Pavement design and construction
- Tack coats and waterproofing seals

International Road Agencies Practices

- New Zealand
- South Africa
- United States of America
- Europe

WA Stripping Cases and Key Findings

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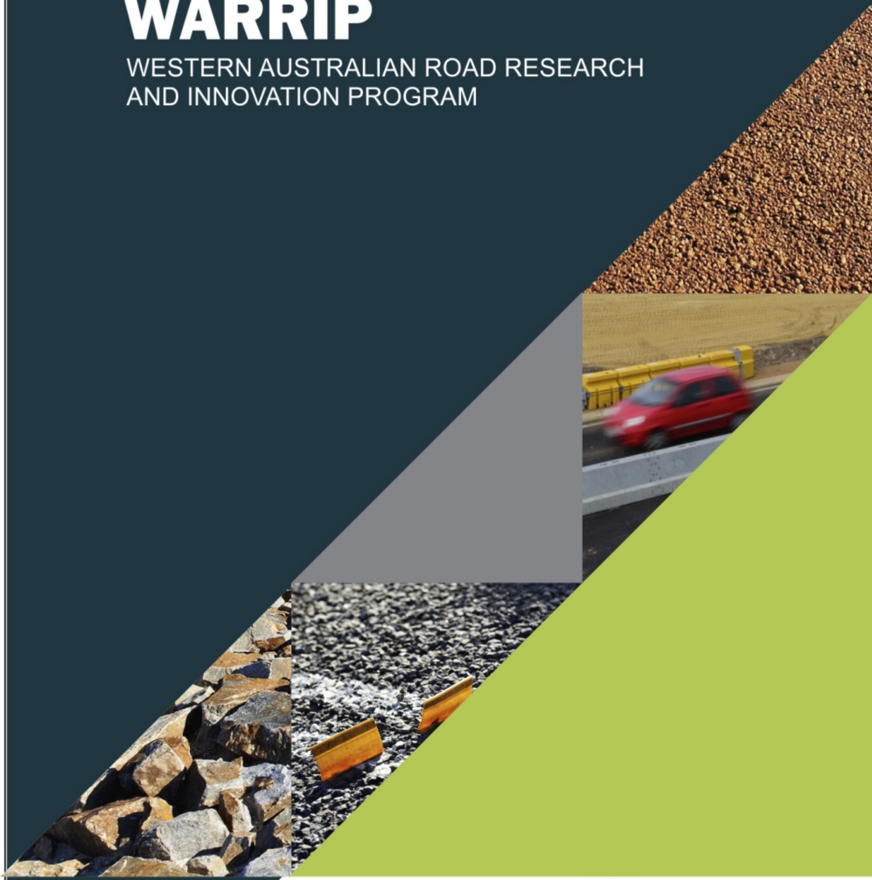

Factors Affecting Asphalt Stripping

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Asphalt Stripping

Moisture Ingress

- **Modes of water ingress into the pavement**
  - Moisture content during asphalt manufacturing
  - Rainfall or other water during asphalt placement
  - Infiltration of surface water (mix permeability)
  - Capillary rise of subsurface water
  - Permeation or diffusion of water vapours
  - Seepage from ditches and high water table (from sides and bottom)
- **Potential sources of water**
  - Water in aggregate before mix manufacture (inadequate drying process)
  - Rainfall or water carts – water flow through and resides within connected macro-spaces of asphalt wearing surface (e.g. OGA) and interconnected voids (e.g. DGA)

Asphalt Stripping

General Stripping Mechanisms

- Moisture damage is either rapid or progressive functional deterioration of the pavement mixture by loss of the bitumen adhesion to aggregate and/or loss of cohesion within the bituminous binder

- Following mechanisms of stripping have been identified in literature review:
  - Detachment
  - Displacement
  - Spontaneous emulsification
  - Pore pressure
  - Hydraulic scouring

Asphalt Stripping

Critical Design Factors

- Dense graded asphalt mixes are generally designed to achieve low air voids of around 3 – 7%.
- Theses mixes are not impermeable even at <7% air voids due to interconnected voids
- Higher in-service temperature results in lower binder viscosity and increased susceptibility to moisture damage
- High traffic loading, high rain fall and poor drainage
- Poor grading and binder content of mix
- Inadequate compaction of asphalt mix
- Excessive dust coating on aggregate and use of friable or weak aggregate
- Use of overlays and seal coats trapping moisture in the pavement
- Aggregate and bitumen type and bitumen viscosity

Asphalt Stripping

Critical Design Factors

- Relationship of theories of adhesive bond loss and stripping mechanisms

Mode of failure	Proposed operation mode	Theory								
		Mechanical interlock			Chemical reaction			Interfacial energy		
Proposed operating mode		P	C	P-C	P	C	P-C	P	C	P-C
Stripping mechanism	Detachment	S						S	W	
	Displacement					S		S		
	Spontaneous Emulsification				S	W				
	Film rupture	S								
	Pore pressure	S								
	Hydraulic scouring	S								
	pH instability					S				S

1 Source: Kiggundu & Roberts (1988).

Key: P: Physical, C: Chemical, P-C: Physical – Chemical, S: Primary contributor, W: Secondary Contributor

Asphalt Stripping

Critical Design Factors

1 Source: Taib et al. (2019).
2 Source: Hicks (1991).
3 Source: Emery & Seddik (1997).
4 Source: Hanz et al. (2007).
5 Source: Choi (2007).
6 Source: Birgisson et al. (2005).
7 Source: Kumar & Anand (2012).

- Factors influencing moisture damage[1]

Factors	Determining characteristics	Favourable properties
Aggregate properties[2,3,4,5]	Surface texture, mineralogy, porosity, surface moisture, surface chemical composition and surface coating	Rough surface texture, carbonaceous aggregate, low silica content, optimum amount of porosity, surface dry aggregate, no coating
Bitumen characteristics[2,5,6]	Asphalt film thickness, viscosity, physical and chemical structure	High asphalt film thickness, high viscosity, existence of phenol and nitrogen
Construction method[3,5,6,7]	Compaction method, drainage system, air voids mechanism	Adequate compaction, proper drainage system, low air void percentages, adapt water resistance additives on each layer of pavement
Environmental condition[2,5]	Climates, environmental temperature	Warm climates, mild temperature (low rate of changing in temperature), no freeze-thaw cycles
Imposed traffic load[2]	Traffic load	Low traffic

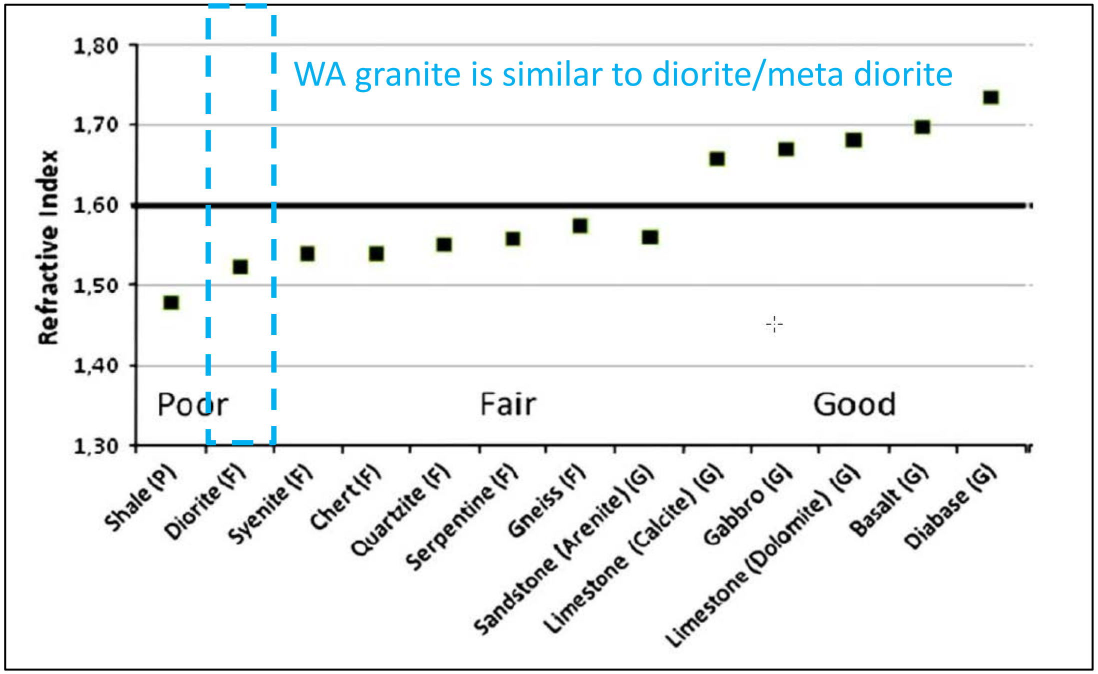
Asphalt Stripping

Aggregate Type and Mineralogy

Key: P: Poor, F: Fair, G: Good.
Source: Soenen et al. (2020).

Hydrophobic vs Hydrophilic

- Basic aggregates generally form stronger bonds with bitumen as compared to acidic aggregates
- Stripping is higher in mixes with aggregates having high concentration of acid insoluble (SiO_2 & Al_2O_3)
- Choice of aggregate type is more dominant factor than bitumen type



Aggregate/mineral refractive index (RI) vs degree of resistance to stripping

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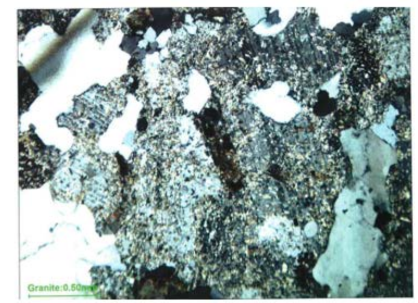
Aggregate Petrography

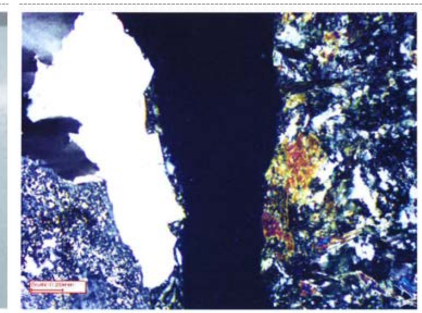
Quarry/Source	Sample type	Rock type identified	Durable minerals		Soft, weak & deleterious minerals	
			Mineral	Content (%)	Mineral	Content (%)
Sample 1: WA Orange Grove Quarry	Nominal 14 mm aggregate	Granite (more precisely adamellite) and subordinate meta-dolerite	Quartz	26	Sericite	5
			Plagioclase feldspar	45	Biotite	5
			K-feldspar (microcline)	5	Chlorite	1
			Epidote	8	Calcite	1
			Actinolite	4	-	-
			Sphene	1	-	-
			Others	< 1	-	-
Sample 2: WA Orange Grove Quarry	Nominal 14 mm aggregate	Granite (more precisely adamellite) and meta-dolerite	Quartz	17	Sericite	6
			Plagioclase feldspar	24	Biotite	1
			K-feldspar (microcline)	16	Chlorite	1
			Epidote	12	Pyrite	1
			Actinolite	17	Calcite	< 1
			Sphene	5	-	-
			Others	< 1	-	-

Sample 1: Image of supplied aggregate sample



Sample 1: Image of granite in cross polarised light at 4x magnification. Plagioclase crystals with sericite and epidote alteration concentrated along cleavage. White grains are anhedral quartz.

Sample 2: Image supplied aggregate sample



Sample 2: Image of two different rock fragments seen in the provided sample – granite (left) and greenstone (right). Image was taken at low magnification with transmitted cross polarised light. Note sericite and epidote alteration throughout the plagioclase in the granite as well as the abundant actinolite, epidote and sphene within the greenstone.

Asphalt Stripping

Testing Procedures

- Mechanism or combination of mechanisms of moisture damage

NOT DEFINITIVE

- Fast, economical, repeatable and reproducible asphalt resistance to moisture test

DOES NOT EXIST

Moisture sensitivity is studied in:

- Individual mix components (binder, aggregate, additive)
- Loose asphalt mixes
- Compacted asphalt mixes
- Mixes in a pavement under field conditions

- Some SRAs use tests to assess asphalt sensitivity to moisture e.g. RMS T230 test method to test single sized unprecoated aggregate without adhesion agent (Plate or Stripping test)
- Main Roads specifies TSR wet strength and wet/dry strength ratio

Asphalt Stripping

Construction Considerations

- **In situ air voids content**
  - Air voids → Permeability → Moisture susceptibility
    - < 4 – 5% air voids generally not interconnected – almost impervious
    - Most DGA mixes are designed to have 3 – 6% air voids
    - USA road agencies generally specify 8% air voids as constructed

- **Compaction of asphalt mix**
  - Poor compaction may result in higher than specified air voids at the time of construction → lack of cohesion, premature surface ravelling
  - Asphalt permeability is dependent on:
    - Air voids, lift thickness, mix type, grading (reduced for finer and increased for coarser mixes)
    - Maximum nominal size of the mix

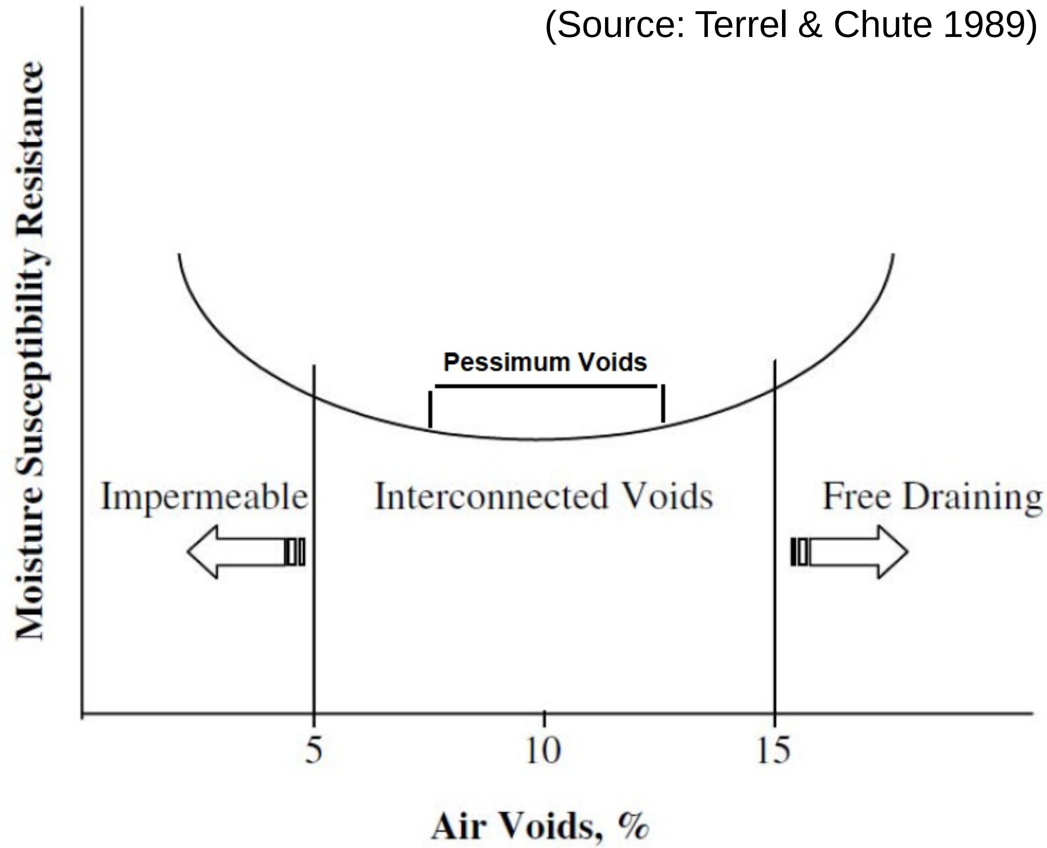
Asphalt Stripping

Critical Design Factors

- Air voids are a key critical factor in the moisture sensitivity of asphalt.

- Asphalt mixes are generally designed below pessimum voids.

(Source: Terrel & Chute 1989)



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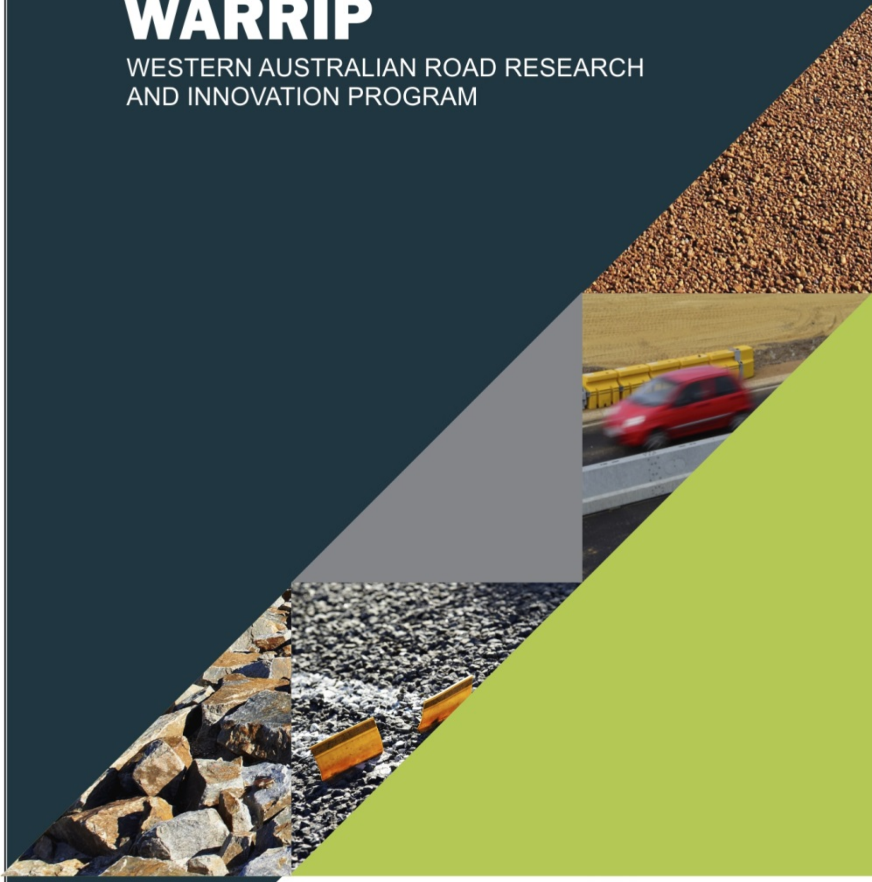

Comparison of Australian SRAs Practices

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Comparison of Australian SRAs Practices

DGA Volumetric Requirements

Jurisdiction	Mix size	Laboratory compaction level	Laboratory compacted air voids (%)		VMA (%)	FBR	BFI
			Min.	Max.	Min.		
Main Roads[1]	14 mm	75 blows (Marshall)	3.5	5.5	14	–	≥ 8.0
	20 mm						
TfNSW[2]	14 mm	120 cycles (Gyratory)	3	6	15	0.8–1.2	> 7.5
		350 cycles (Gyratory)	2.0	N/A			
	20 mm	120 cycles (Gyratory)	3	6	14		
		350 cycles (Gyratory)	2	N/A			
DoT Vic[3]	14 mm	50 blows (Marshall)	4.9	5.3	15	–	–
	20 mm				14		9.5
	20 mm	80 cycles (Gyratory)	2	N/A	N/A		–
TMR[4]	14 mm	50 blows (Marshall) or (120 and 350 cycles (Gyratory))	3.0 (2.0)	6.0 (N/A)	N/A	1.0–1.3	> 7.5
	20 mm	50 blows (Marshall) or (120 and 350 cycles (Gyratory))			N/A		
DIT[5]	10 mm	50 and 80 cycles (Gyratory)	4.0		N/A	–	9.5, 8.5
	14 mm	50 and 80 cycles (Gyratory)	4.0		N/A		–
IPWEA[6]	14 mm	50 blows (Marshall)	4.0	6.0	14	–	≥ 7.0
	20 mm	80 blows (Marshall)					

1. Source: Main Roads (2022a).
2. Source: TfNSW (2021).
3. Source: VicRoads (2021).
4. Source: TMR (2022a).
5. Source: DIT (2022).
6. Source: IPWEA (2016).

Key: FBR: Filler/binder ratio, BFI: Binder film index.

Comparison of Australian SRAs Practices

DGA Performance-related Requirements

Jurisdiction	Property	Test method	Requirements
Main Roads[(1)]	Stability (kN) Flow (mm)	WA 731.1-2018 (Main Roads 2018a)	8 (min.) 2–4
	Deformation resistance (mm)	AGPT/T231-06 (Austroads 2006b)	4 (max.)
	Tensile strength ratio (TSR, %)	AGPT-T232-07 (Austroads 2007a)	80% (min.)
TfNSW[(2)]	Tensile strength ratio (TSR, %)	RMS T640 (RMS 2012c)	80% (min.)
DoT Vic[(3)]	Tensile strength ratio (TSR, %) Indirect tensile modulus (MPa) Deformation resistance (mm)	AG:PT/T232-07 (Austroads 2007a) AS/NZS 2891.13.1 AGPT-T231-06 (Austroads 2006b)	80% (min.) 3,000–7,000 4 (max.)
TMR[(4)]	Stability (kN) Flow (mm) Stiffness Tensile strength ratio (TSR, %) Resilient modulus (MPa) Deformation resistance (mm)	Q305 (TMR 2022c) Q305 (TMR 2022c) Q305 (TMR 2022c) Q315 (TMR 2022d) or AGPT/T232-07 (Austroads 2007a) AS/NZS 2891.13.1:2013 AGPT-T231-06 (Austroads 2006b)	7.5 (min.) 2 (min.) 2.0 kN/mm 80% (min.) Report only 4.5 mm (max.) 3.5 (max.) for PMB
DIT[(5)]	Indirect tensile strength (kPa) Resilient modulus (MPa) Deformation resistance (mm) Flexural fatigue (min. microstrain at 1 million cycles)	DPTI:TP460-2013 (DPTI 2013) AS/NZS 2891.13.1:2013 AGPT-T231-06 (Austroads 2006b) DPTI:TP477-2015 (DPTI 2015)	Report only 2,400–6,600 3.0–6.0 170 (AC14M320) 150 (AC20M320)
IPWEA[(6)]	Stability (kN)	N/A	6.5 (50 blows) 8.0 (80 blows)
	Flow (mm)	N/A	2–4

1. Source: Main Roads (2022a).
2. Source: TfNSW (2021).
3. Source: VicRoads (2021).
4. Source: TMR (2022a).
5. Source: DIT (2022).
6. Source: IPWEA (2016).

Comparison of Australian SRAs Practices

DGA Field Compaction Requirements

Relaxed to 7% to allow 4% production tolerance

Jurisdiction	Mix size	In situ air voids (%)[1]		Density ratio (%)[2]
		Min.	Max.	Min.
Main Roads[3]	14 mm and 20 mm	3	6	Not specified
TfNSW[4]	14 mm and 20 mm	3	7	Not specified
DoT Vic[5]	14 mm and 20 mm	Not specified	Not specified	96% characteristic value of Marshall density or 97% mean value of density ratio [9]
TMR[6]	14 mm and 20 mm surface layer Covered by 2 AC layers Covered by 3 AC layers	 3 2.5 2	 7 7 7	Not specified
DIT[7]	10 mm	4	8	Not specified
	14 mm	2.5	7	Not specified
IPWEA[8]	14 mm and 20 mm	1.5	7	Not Specified

1. Based on characteristic values.
2. Ratio between the bulk density of field cores and Marshall density.
3. Source: Main Roads (2022a). Maximum characteristic value for in situ air voids is relaxed to 7% to allow for asphalt suppliers to implement new asphalt mix designs and construction practices.
4. Source: TfNSW (2021). Upper limit for characteristic values of in situ air voids is 8% for specified layer thickness of > 30 mm and < 50 mm.
5. Source: VicRoads (2021).
6. Source: TMR (2022a).
7. Source: DIT (2021).
8. Source: IPWEA (2016).
9. Characteristic value used where 6 or more tests are available.

Comparison of Australian SRAs Practices

Tack Coat and Waterproofing Seal

- Main Roads specifies:
  - A sprayed bituminous seal on the size 14 mm asphalt intermediate course
  - A tack coat of diluted emulsion on the prepared surface
  - CRS170-60 for tack coat @ 0.6 litres/m^2 of residual binder

- TfNSW specifies:
  - A prime or sprayed seal between thin (≤ 50 mm) and a low cutter seal for thicker (> 50 mm) asphalt layers over granular base

Comparison of Australian SRAs Practices

Tack Coat and Waterproofing Seal

- TMR specifies the tack coat @ 0.10 – 0.30 litres/m^2 of residual binder
- TMR also specifies waterproofing seal in DSA and FDA pavements (can be omitted under DGA and SMA when asphalt contractor demonstrates a history of conformance with the in situ air voids requirements)
- TfNSW, TMR and VicRoads specify double application rate of CRS/170-60 tack coat on joints
- DIT specifies CRS grade emulsion for the tack coat at vertical edges between old and new pavement, and on the top of existing asphalt layers or new asphalt not placed on the same day

Comparison of Australian SRAs Practices

SMA Volumetric Requirements

- TfNSW and DIT specify gyratory compaction whereas all other SRAs specify a 50 blows Marshall compaction level.

Jurisdiction	Mix size	Laboratory compaction level	Laboratory compacted air voids (%)		VMA (%)
			Min.	Max.	Min
Main Roads[1]	7 mm	50 blows (Marshall)	3.0	5.0	19
	10 mm		3.5	5.5	18
TfNSW[2]	10 mm	120 cycles (Gyratory)	3.5	6.5	N/A
		350 cycles (Gyratory)	2.0	N/A	
	14 mm	120 cycles (Gyratory)	3.5	6.5	N/A
		350 cycles (Gyratory)	2.5	N/A	
DoT Vic[3]	10 mm (normal)	50 blows (Marshall)	3.5	5.0	18
	10 mm (HD)		4.8	5.2	18
TMR[4]	10 mm	50 blows (Marshall)	2	5	N/A
	14 mm	50 blows (Marshall)			N/A
DIT[5]	7 mm	80 cycles (Gyratory)	3.5		N/A
	10 mm	80 cycles (Gyratory)			N/A
Austroads[6]	7 mm	50 blows (Marshall – normal/medium duty) or 80 cycles Gyratory normal/medium duty) 75 blows (Marshall – HD) or 120 cycles Gyratory – HD	3.5	4.5	19
	10 mm		3.5	4.5	18
	14 mm		3.5	4.5	17
IPWEA[7]	7 mm, 10 mm and 14 mm	50 blows (Marshall) or 80 cycles (Gyratory)	3.5	3.5	N/A

1. Source: Main Roads (2022b).
2. Source: TfNSW (2020c).
3. Source: VicRoads (2018b).
4. Source: TMR (2022a).
5. Source: DIT (2022).
6. Source: Austroads (2007b).
7. Source: IPWEA (2016).

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Comparison of Australian SRAs Practices

SMA Performance-related Requirements

Jurisdiction	Property	Test method	Requirements
Main Roads[(1)]	Stability (kN) Flow (mm)	WA 731.1-2018 (Main Roads 2018a)	6 (min.) 2–5
TfNSW[(2)]	Deformation resistance (mm)	AGPT/T231-06 (Austroads 2006b)	2.5 (max.)
DoT Vic[(3)]	Stability (kN) Resilient modulus (MPa)	AS/NZS 2891.5:2015 AS/NZS 2891.13.1:2013	5.5 (min.) Report only
TMR[(4)]	Resilient modulus (MPa) Deformation resistance (mm)	AS/NZS 2891.13.1:2013 AGPT/T231-06 (Austroads 2006b)	Report only 2.0 (max.)
DIT[(5)]	Indirect tensile strength Deformation resistance (mm) Flexural fatigue (min. microstrain at 1 million cycles)	DPTI:TP460-2013 (DPTI 2013) AGPT/T231-06 (Austroads 2006b) DPTI:TP477-2015 (DPTI 2015)	Report only 3.0 (max.) 350 (SMA 10M15E) 250 (SMA 10M5EP)
	Resilient modulus (MPa)	AS/NZS 2891.13.1:2013	1,000–3,000
			4,000–6,000
IPWEA[(6)]	Cantabro abrasion loss (%)	Not specified	25 (unconditioned) 35 (conditioned)

1. Source: Main Roads (2022b).
2. Source: TfNSW (2020c).
3. Source: VicRoads (2018b).
4. Source: TMR (2022a).
5. Source: DIT (2022).
6. Source: IPWEA (2016).

Comparison of Australian SRAs Practices

SMA Field Compaction Requirements

Jurisdiction	Mix size	In situ air voids (%)[1]		Density ratio (%)[2]
		Min.	Max.	Min.
Main Roads[3]	7 mm and 10 mm	Not specified	Not specified	95% characteristic value of Marshall density
TfNSW[4]	10 mm and 14 mm	3	7	Not specified
DoT Vic[5]	10 mm (normal or heavy duty)	Not specified	Not specified	96% characteristic value of Marshall density or 97.5% mean value of density ratio[9]
TMR[6]	10 mm	2	7	Not specified
	14 mm	2	6	
DIT[7]	7 mm and 10 mm	1	5	Not specified
IPWEA[8]	7 mm, 10 mm and 14 mm	3.5	10	Not specified

1. Based on characteristic values.
2. Ratio between the bulk density of field cores and Marshall density.
3. Source: Main Roads (2022b).
4. Source: TfNSW (2020c).
5. Source: VicRoads (2018b).
6. Source: TMR (2022a).
7. Source: DIT (2021).
8. Source: IPWEA (2016).
9. Characteristic value used where 6 or more tests are available.

Comparison of Australian SRAs Practices

OGA Volumetric Requirements

Jurisdiction	Mix size	Laboratory compaction level	Laboratory compacted air voids (%)		BFI
			Min.	Max.	(microns)
Main Roads[1]	10 mm	75 blows (Marshall)	16.0	21.0	Not specified
TfNSW[2]	10 mm	80 cycles (Gyratory)	20.0	25.0	> 15
	14 mm				
DoT Vic[3]	10 mm	50–80 cycles (Gyratory)	18.0	25.0	> 20
TMR[4]	10 mm	50 blows (Marshall)	20.0	N/A	> 16
	14 mm	50 blows (Marshall)			
DIT[5]	10 mm	80 cycles (Gyratory)	18	20.0	Not specified
	14 mm	80 cycles (Gyratory)			

1. Source: Main Roads (2022c).
2. Source: TfNSW (2020d).
3. Source: VicRoads (2018b).
4. Source: TMR (2022a).
5. Source: DIT (2022).

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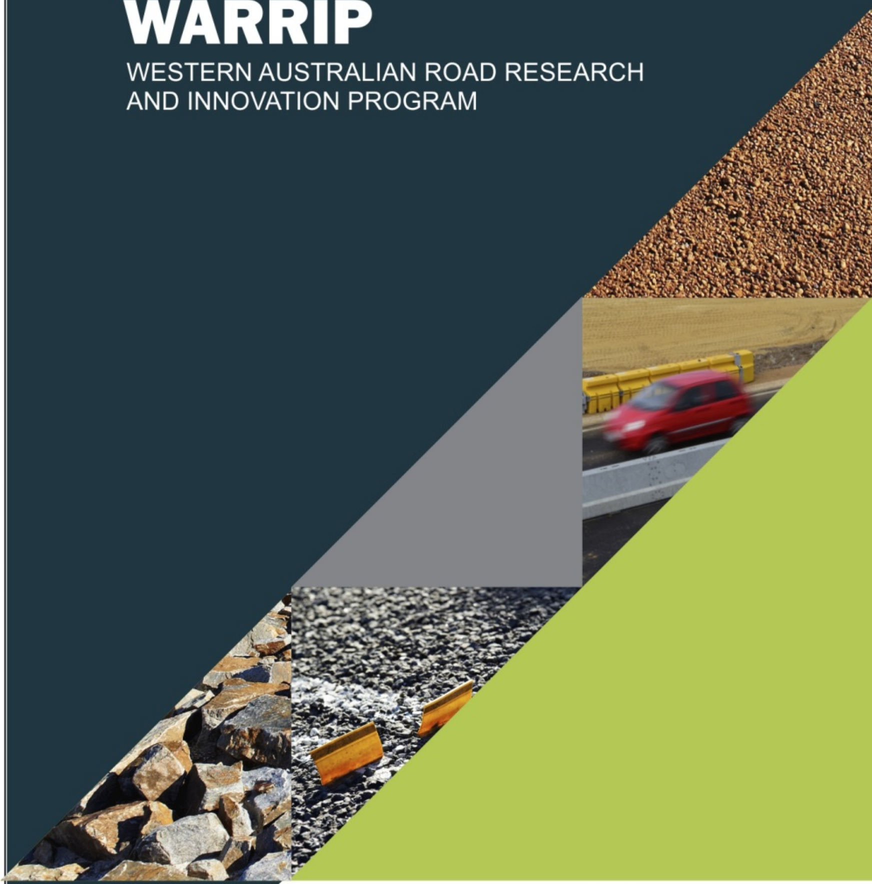

Stripping Occurrences on Main Roads projects

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Stripping Occurrences

- Main Roads observed the effects of moisture in thick lift asphalt (TLA) and FDA on a number of sites.

New Perth Bunbury Highway

- 30 mm OGA10, C320
- 30 mm OGA10, C170
- 130 mm AIC20, C320
- 60 mm high binder layer AIC20, C320

➢ High binder layer was flagged as a non-conforming design but were argued to be beneficial deviations.

➢ Raised concerns about degree of compaction and void contents along the cold construction joints within the pavement.

New Perth Bunbury Highway

Photo 1: Water seepage from underneath 20mm intermediate mix after rain shower.

Photo 2: View of the wet core showing some of the voids at the interface.

SLK 54 - 51

1A	2A	3A	4A	5A	6A	7A
Breakdown Lane	LL LWL	LL RWP	Centre Line	RL LWP	RL RWP	Right Shoulder

Top

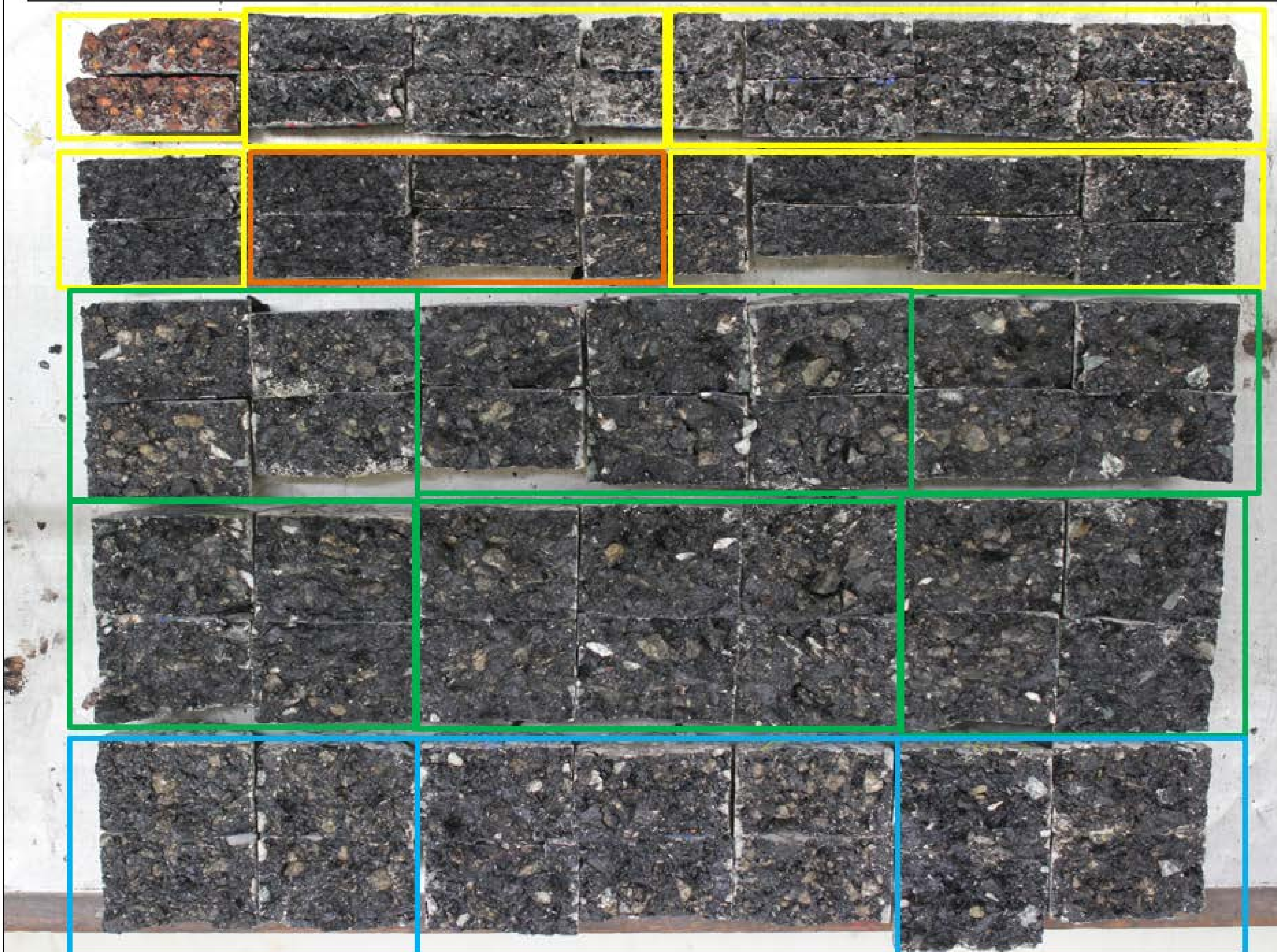
10mm OGA

10mm DGA

20mm ICA

20mm ICA

20mm BCA



Stripping Occurrences in WA

Great Eastern Highway, Greenmount

- Thick lift asphalt showing moisture within the lower portion of the placed asphalt, some of which disintegrated upon removal
- Fluctuating water levels, above and below ground level

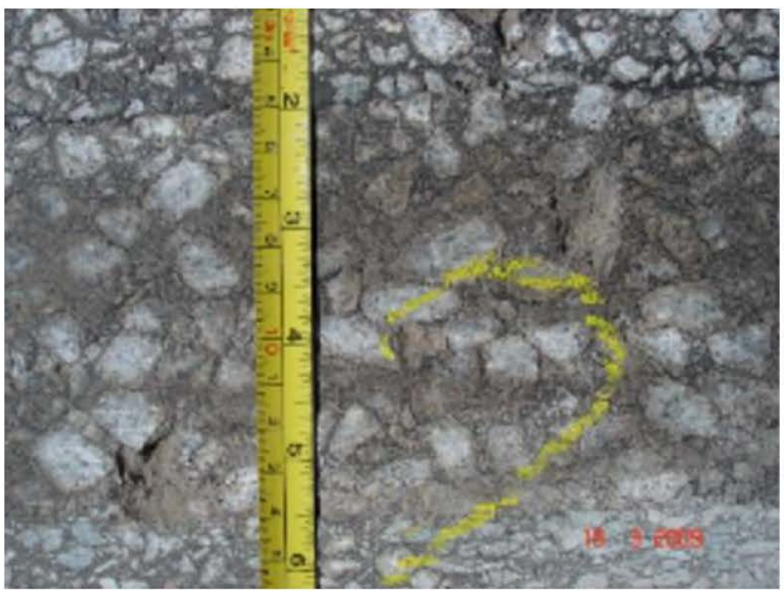


Photo 1: Pavement with three layers of asphalt approximately 200 mm thick.

Photo 2: A view of face of the hole.

Stripping Occurrences in WA

Great Eastern Highway and Roe Highway Interchange (GERI)

- Rutting developed in the DG14 intermediate layer after opening to temporary traffic in 2012, prior to placing waterproof seal
- Investigation revealed that stripping had occurred in the uppermost layer of DG20, with 11 of 36 cores disintegrating during coring.

Pavement Type D (PTD)	
DGA 14 mm (A15E PMB)	50mm
DGA 14 mm (A35P PMB)	40mm
DGA 20 mm (A35P PMB)	60mm
DGA 20 mm Class 320 bitumen – 260 mm	260 mm
Crushed Limestone sub-base	200mm
Select fill subbase	-
Sandy clay layer	-

Pavement Type E (PTE)	
DGA 14 mm (Class 320 Bitumen)	40mm
DGA 20 mm (C320)	205mm
Crushed Limestone sub-base	200mm
Select fill subbase	-
Sandy clay layer	-

Pavement Type F (PTF)	
DGA 14 mm (Class 320 Bitumen)	40mm
DGA 20 mm (C320)	180mm
Crushed Limestone sub-base	200mm
Select fill subbase	-
Sandy clay layer	-

Great Eastern Highway and Roe Highway Interchange (GERI)

Photo 1: Stripping leading to voided section in core

Photo 2: Stripping leading to voided section in core

Great Eastern Highway and Roe Highway Interchange (GERI)

Leach Highway, Shelley Bridge

- Shoving occurred within 6 months of placing new SAMI and DGA10 inlay on bridge, with thickness between 70 and 110 mm
- Investigation revealed that the stripping had occurred in the old asphalt below the SAMI.

The Bottom of Core 2, Showing Moisture and Stripped Aggregate

Leach Highway, Shelley Bridge

Core face of Core 3, Showing Weak and Stripped Asphalt in the Lower Layer

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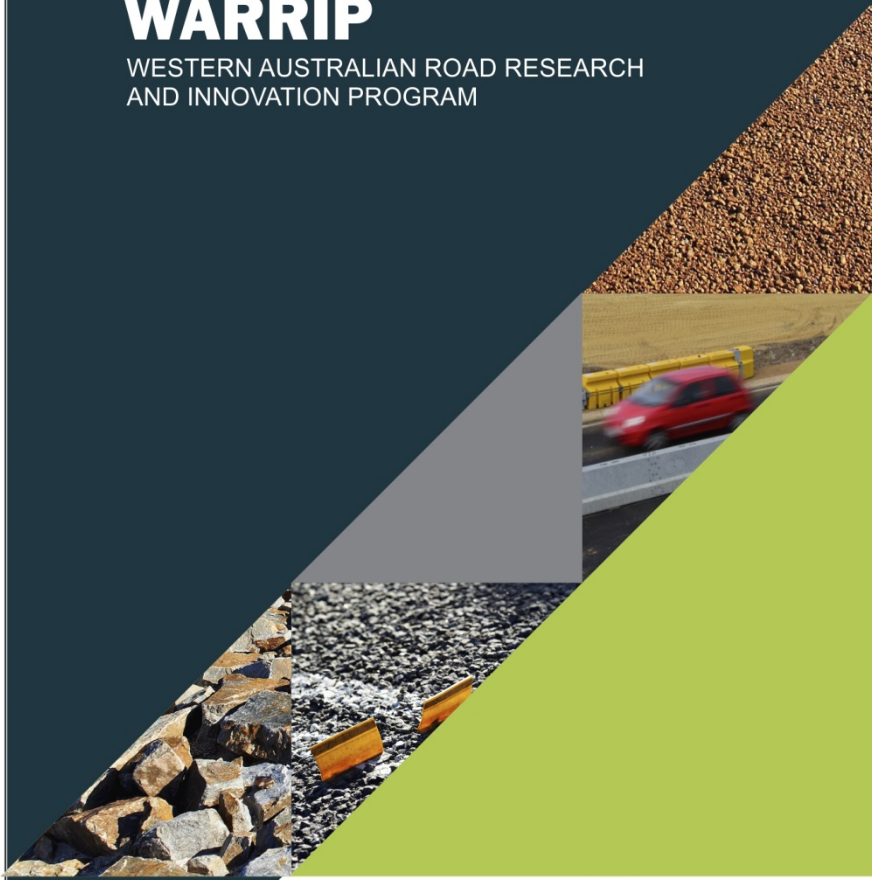

International Road Agencies Practices

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International Road Agencies Practices

Comparison with Main Roads Practice (DGA)

Road Agency	Country	Design air voids %	Compaction level	TSR %	Lab-moulded density
NZTA	New Zealand	3.0	50/75 Marshal blows	75[2]	n/a
SABITA	South Africa	4.0	gyratory cycles	60 – 80[2]	n/a
FHWA	USA	3.0 – 5.0	(gyratory cycles)[1]	80	n/a
TxDOT	USA	n/a	50 gyratory cycles (varies 35 – 100)	n/a	96.5 (max. 97.5)

1 Based on ESAL (million)
2 Modified Lottman Test where Freeze/thaw effect optional, mainly water conditioned

- Europe mix design processes use TSR and HWTT for moisture sensitivity

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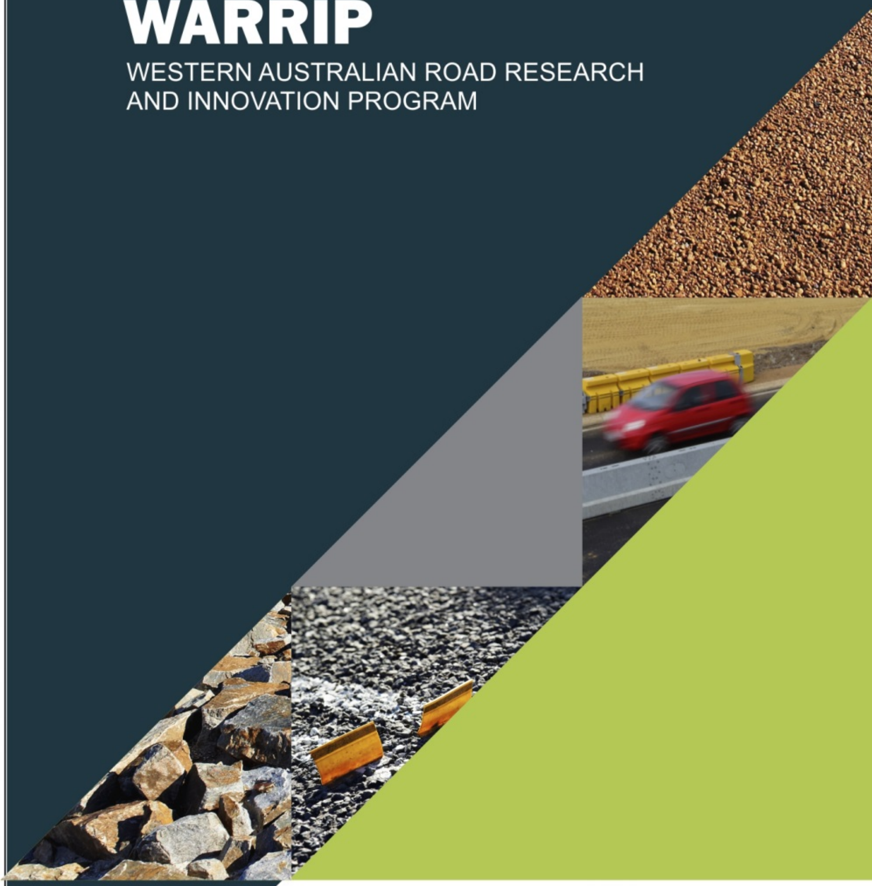

Analysis of Gateway Field Trial

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Main Roads Data

- No data has been collected as a part of this WARRIP project.
- Data analysed was provided by Main Roads.
- Data is based on the Gateway Field Trials (2015-2018).
- Data has been analysed and linkages developed with Main Roads current practice.

Gateway Field Trials

- Gateway Field Trials were constructed in April 2015 on northbound carriageway of Tonkin Highway over the full widths of lanes R1, R2 & R3.
- Four different trial mixes of DG14 and DG20 were constructed, including two new 3rd generation mix designs allowing natural sand.
- Trial sites were opened to traffic in September 2015.
- The purpose of the trials was to investigate the effectiveness of the new 3rd generation mix designs in reducing moisture ingress on the intermediate courses and effect of seal placed.

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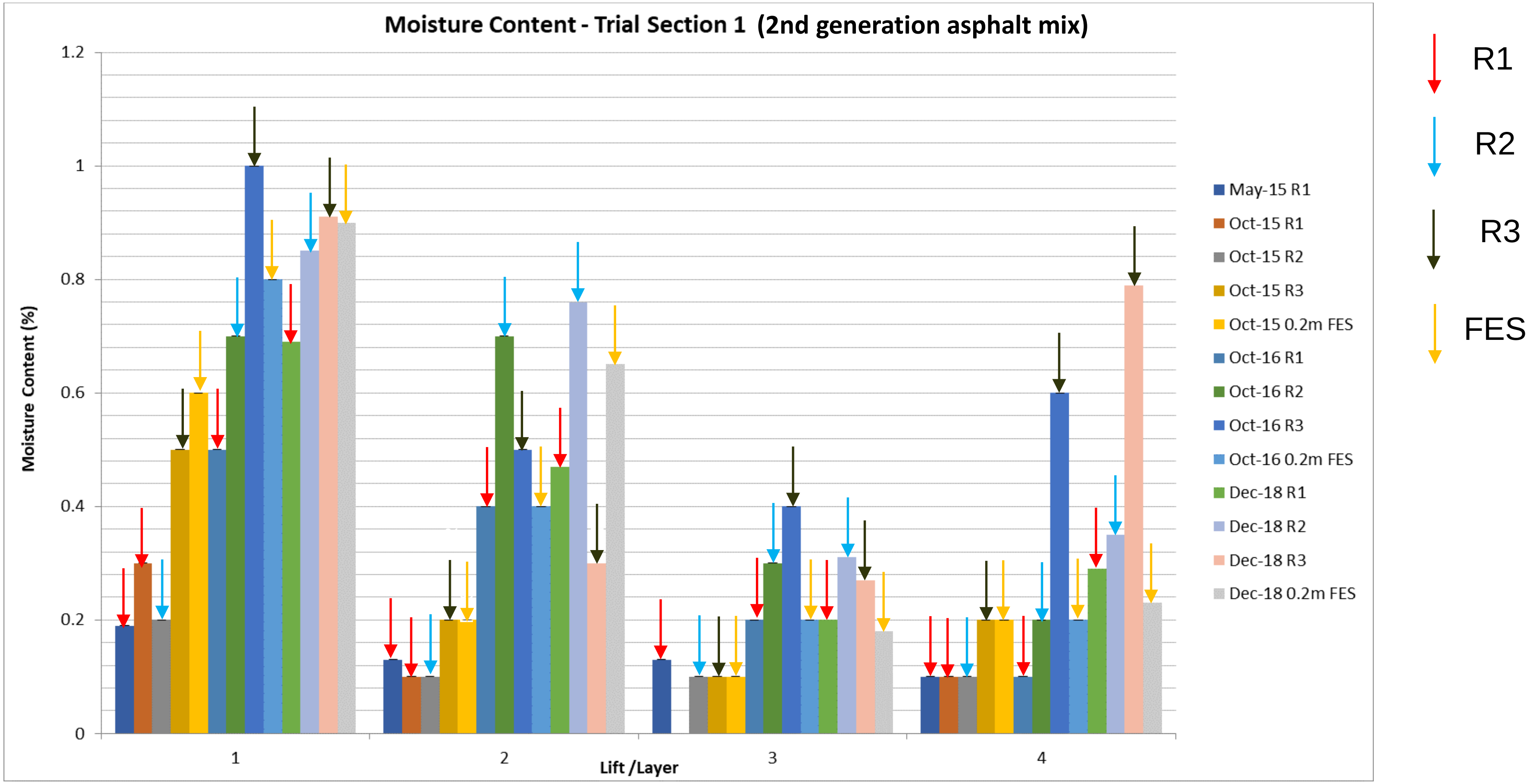
Pavement Structure and Mix Generations

Wearing Course – 10 mm Open Graded Asphalt (Class 320 Bitumen)	-	30 mm
Wearing Course – 14 mm Dense Graded Asphalt (A15E binder)	-	40 mm
Waterproof Seal		
Intermediate Course – 14mm Dense Graded Asphalt (A15E Binder)	Lift 4	50 mm
Intermediate Course – 20 mm Dense Graded Asphalt (Class 600 Bitumen)	Lift 3	185 mm
	Lift 2	
	Lift 1	
Crushed Rock base Subbase	-	200 mm
Sand Subgrade (Perth Sand) Compact requirement: 96% min.	-	300 mm

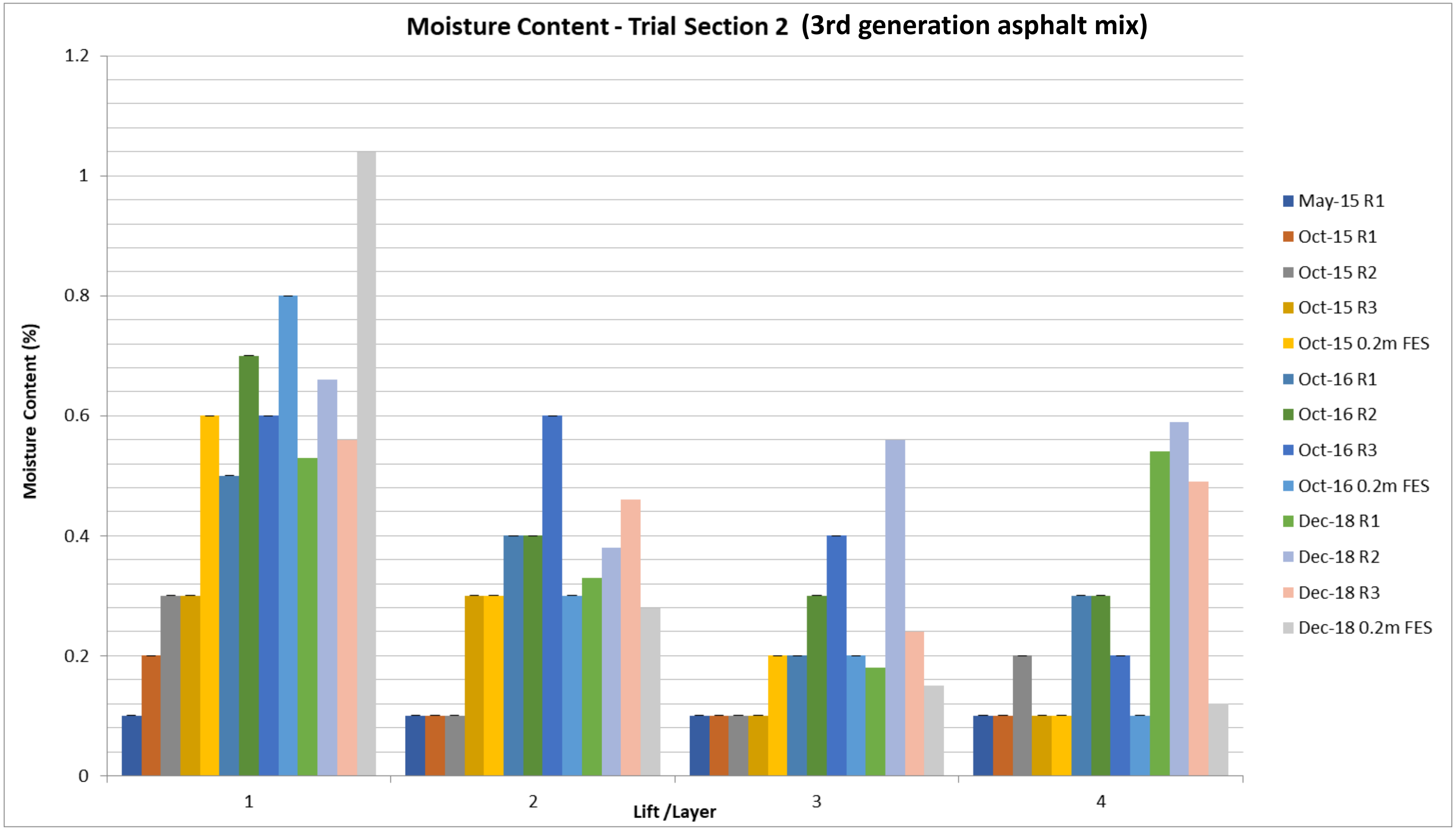
Mix generation	Job mix	Mix type	Nominal size	Marshall blows	Air voids (Marshall) (%)	VMA (%)	VFB (%)	BFI	Air voids (350 gyratory cycles)
2nd generation	A	DGA	20 mm	75	3.5–5.5	14 min	70 min	8.0 min	2.5 min
	B		14 mm		4.0–6.0				
3rd generation	C	DGA	20 mm	75	3.5–5.5	14 min	70 min	8.0 min	2.5 min
	D		14 mm						

Moisture Content



Lift 1 to 3: 20 mm DGA
Lift 4: 14 mm DGA

Moisture Content



Lift 1 to 3: 20 mm DGA
Lift 4: 14 mm DGA

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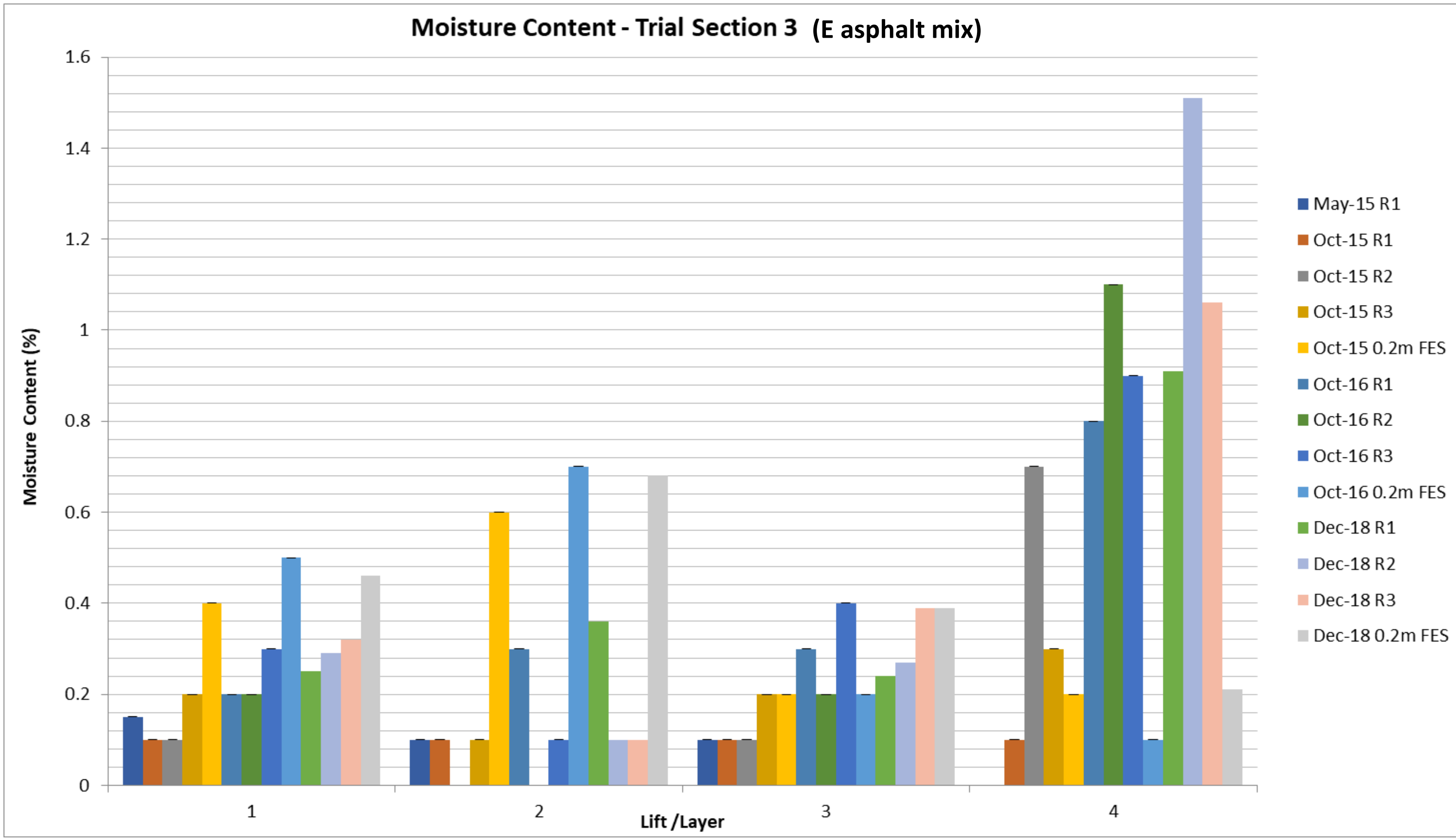
Moisture Content



Lift 1 to 3: 20 mm DGA
Lift 4: 14 mm DGA

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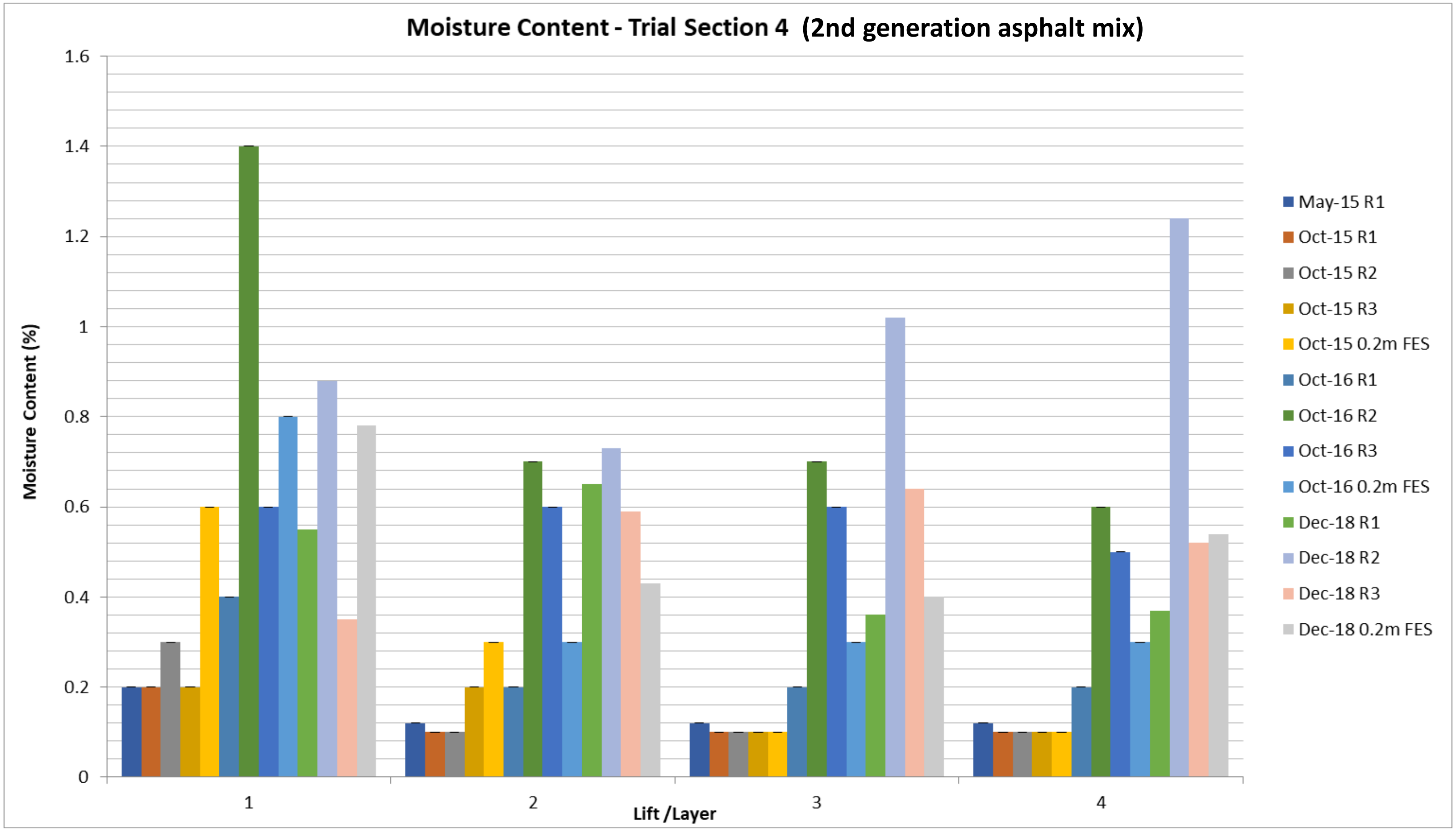
Moisture Content



Lift 1 to 3: 20 mm DGA
Lift 4: 14 mm DGA

Conclusions from moisture content

- All layers of all mixes have moisture content ingress
- Generally, 3rd generation mix is better than 2nd generation mix
- Characteristic air voids lots < 5% are generally better than >5% lots but the data data evidence is not strong .

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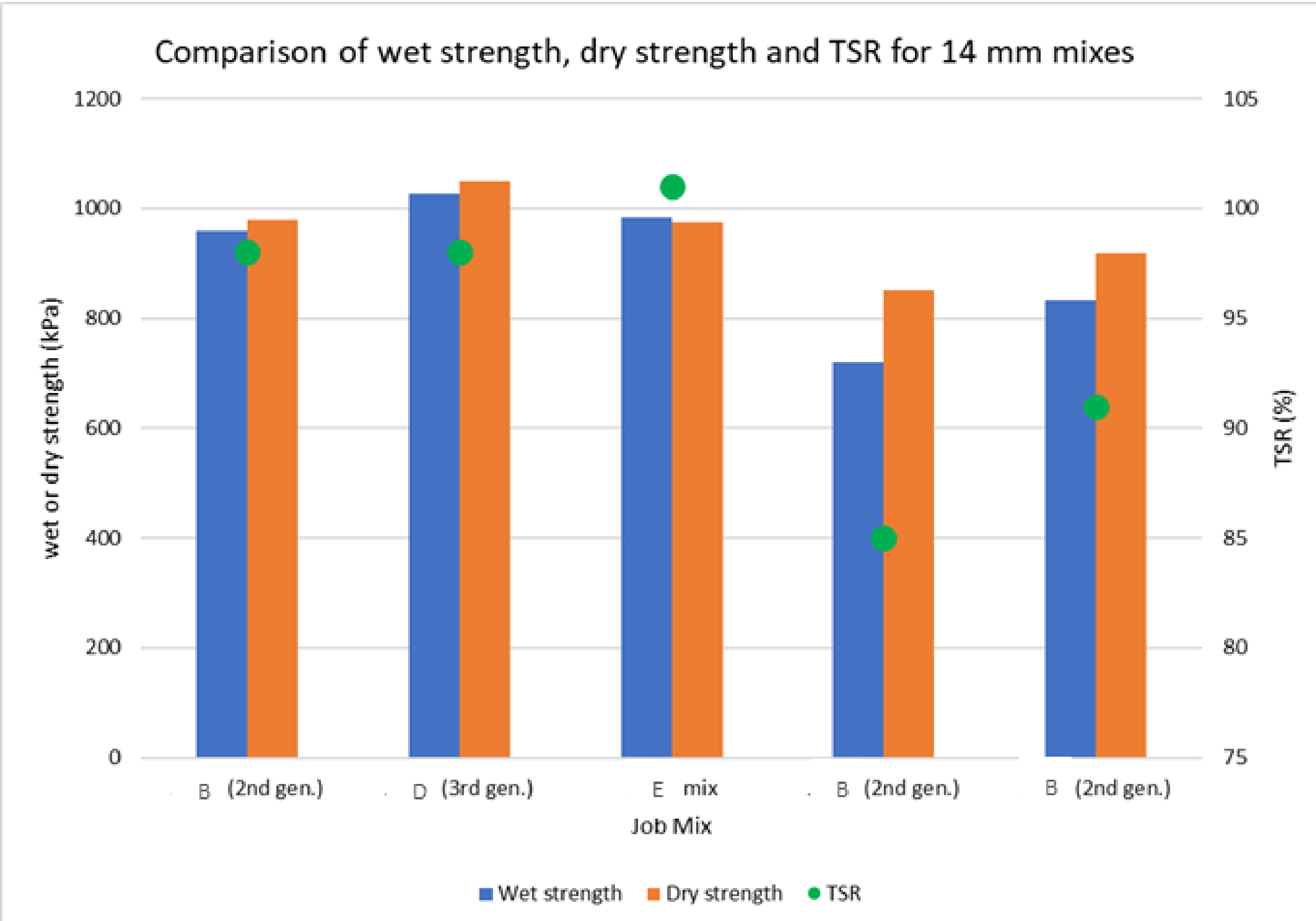
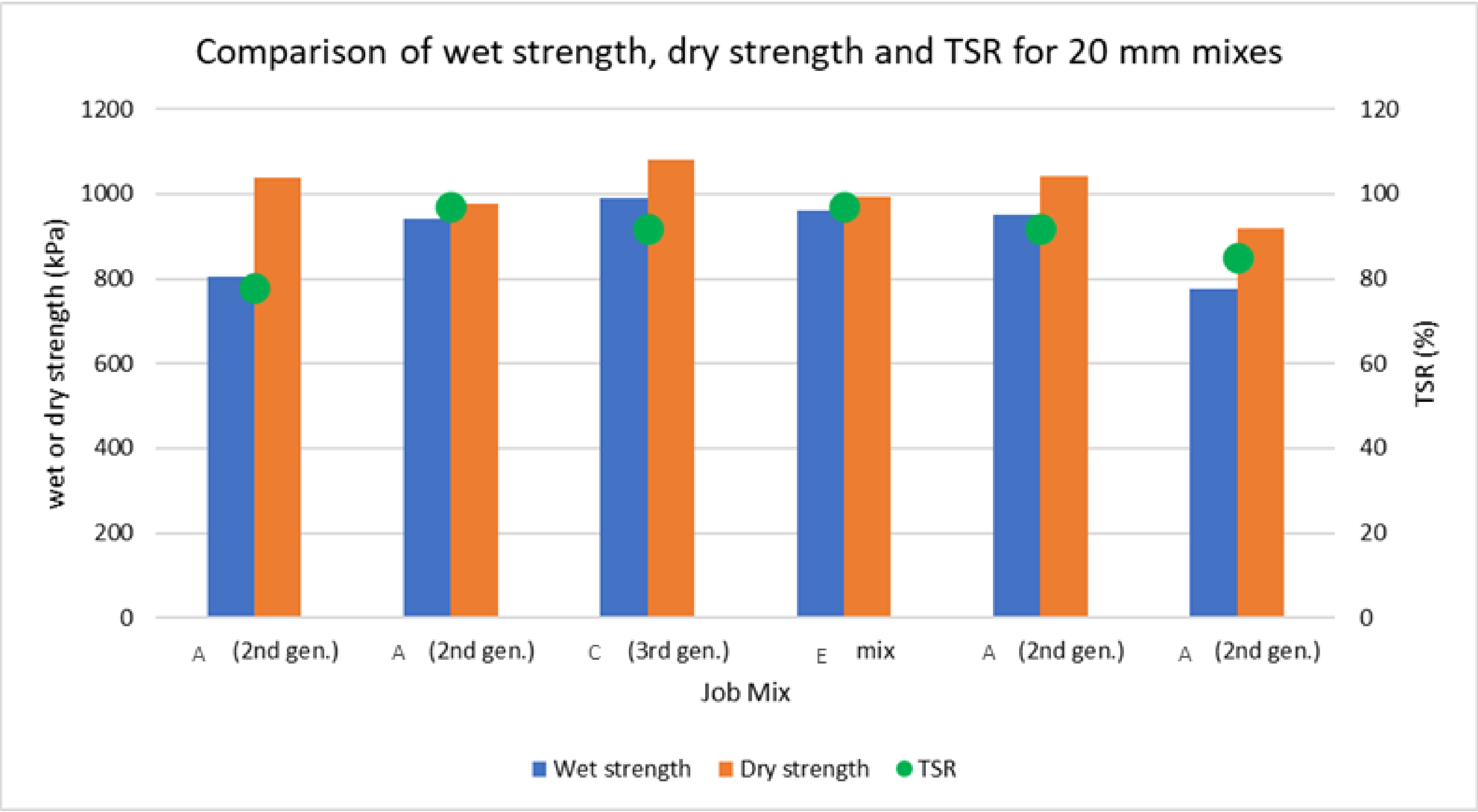
Tensile Strength Ratio (TSR)



Tensile Strength Ratio (TSR)



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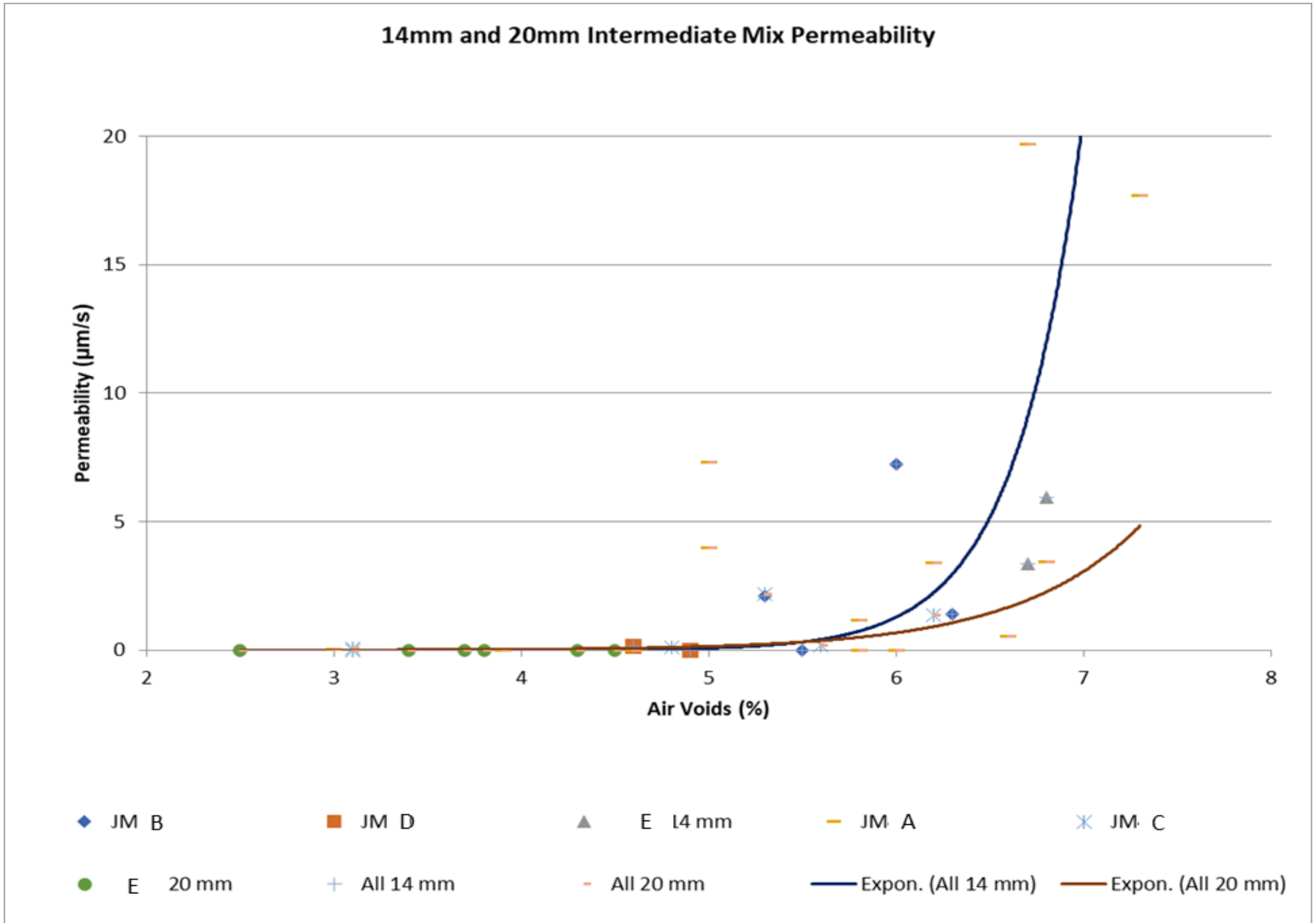
Air Voids and Permeability



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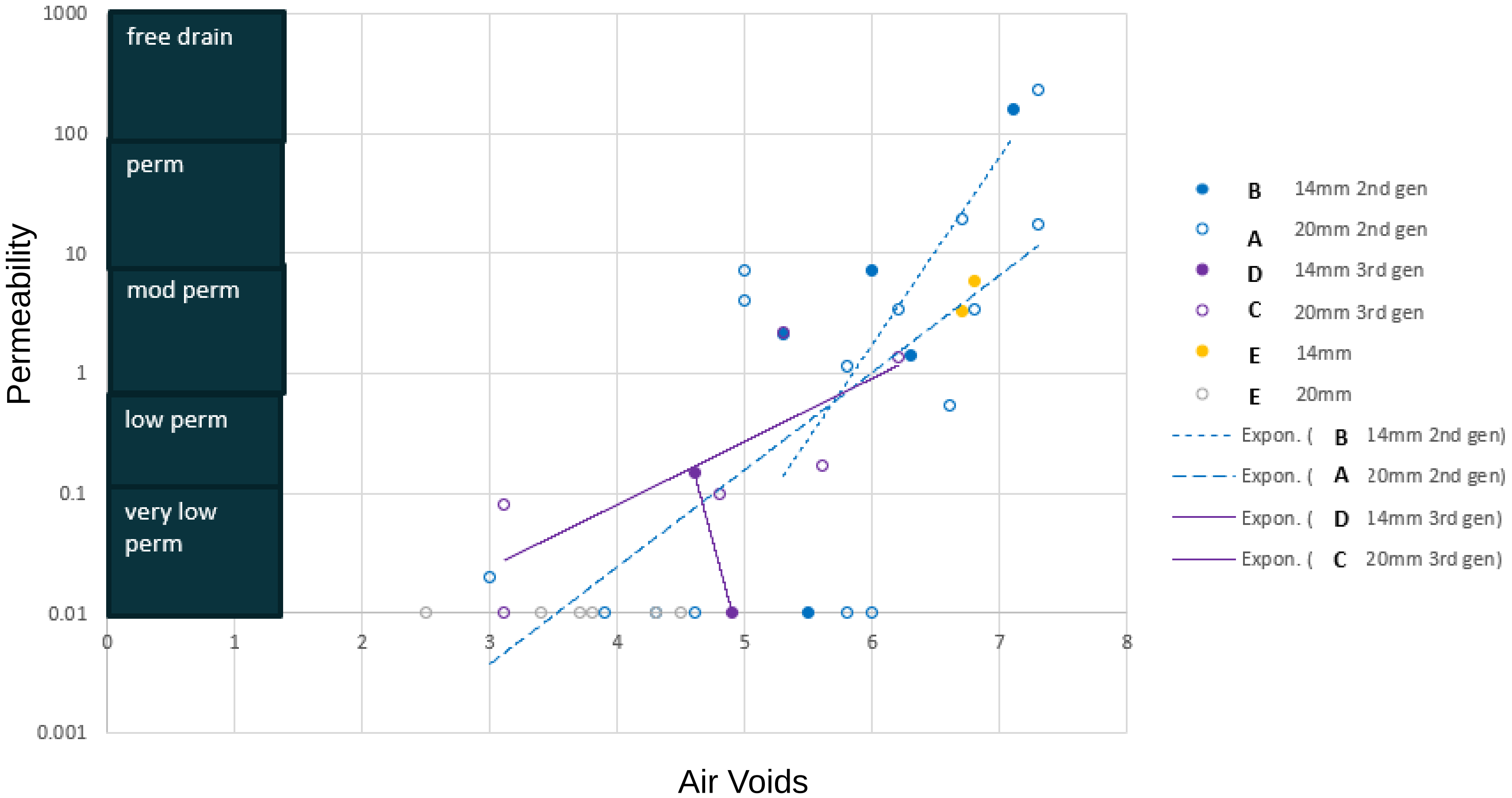
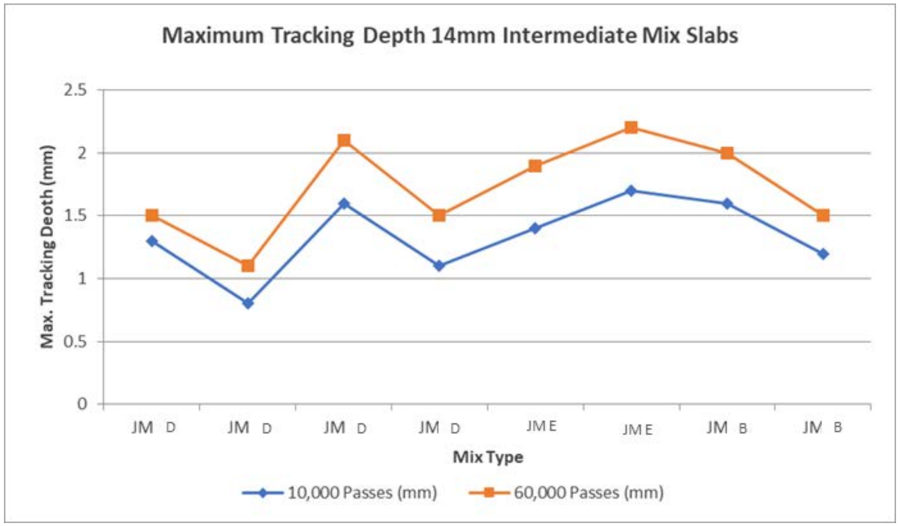
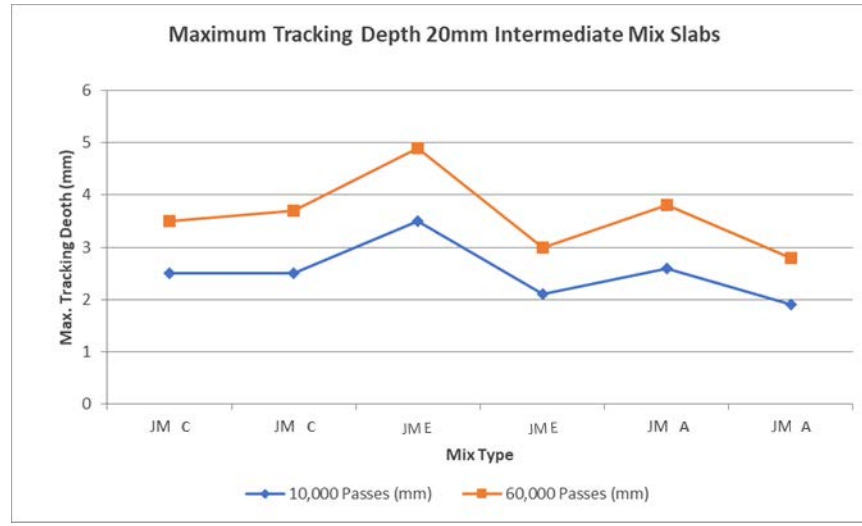
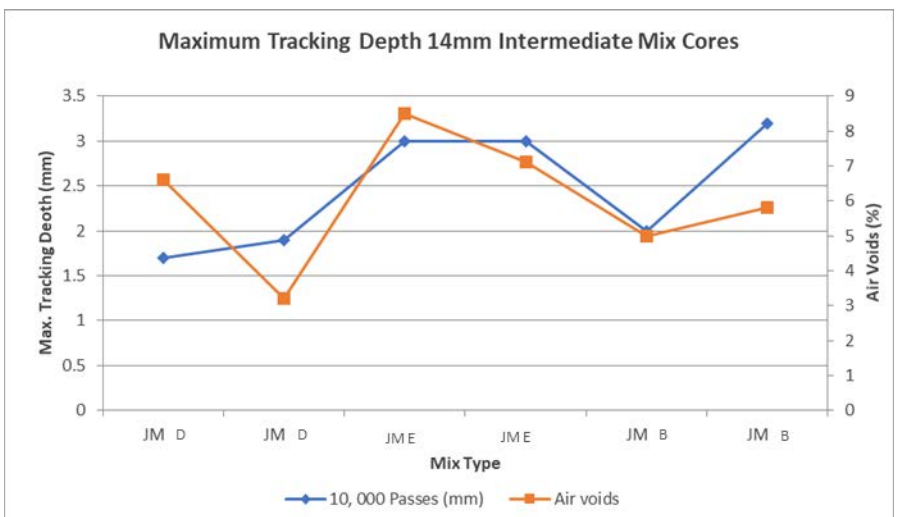
Air Voids and Permeability

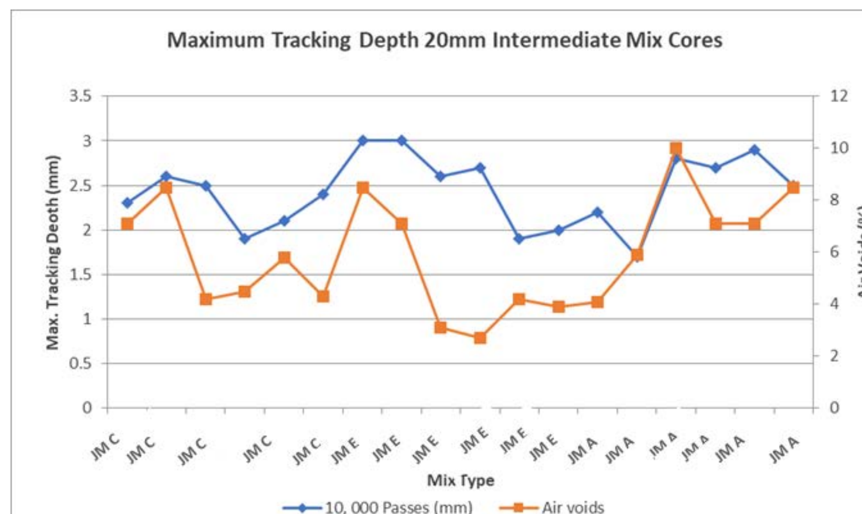


Wheel Tracking Test









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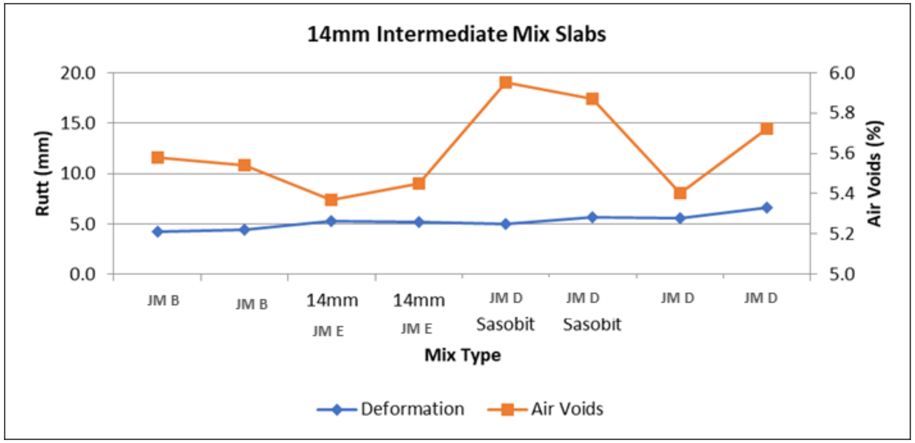
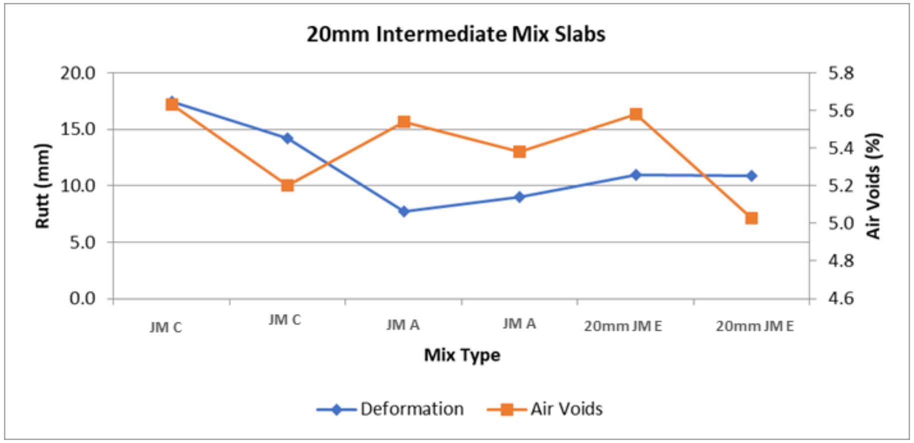
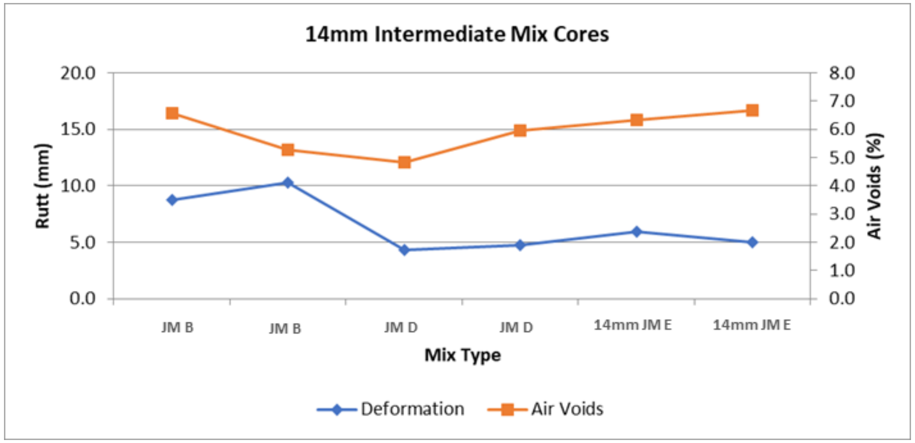
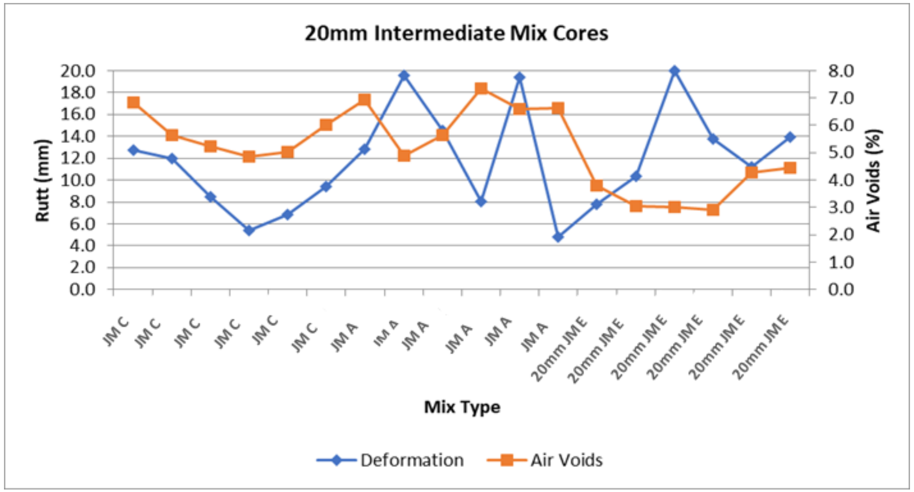
Hamburg Wheel Tracking Test









Conclusions from TSR & wheel tracking

- 3rd generation 14 mm mixes showed higher wet and dry strengths and TSR as compared to 2nd generation mixes – Higher the air voids, lower the wet and dry strength
- 2nd and 3rd generation 20 mm mixes showed wet and dry strength and TSR in similar range – similar air voids
- Wheel tracking depth (10,000 passes) for 3rd generation 14 mm mix is lower than 2nd generation mix: lower air voids lower WT depth (data evidence may not be that strong - very limited testing)
- Wheel tracking depth for 2nd and 3rd generation mixes (60,000 passes) is equal.
- Generally, for wheel tracking depth there is increasing trend for increasing air voids % (limited testing).

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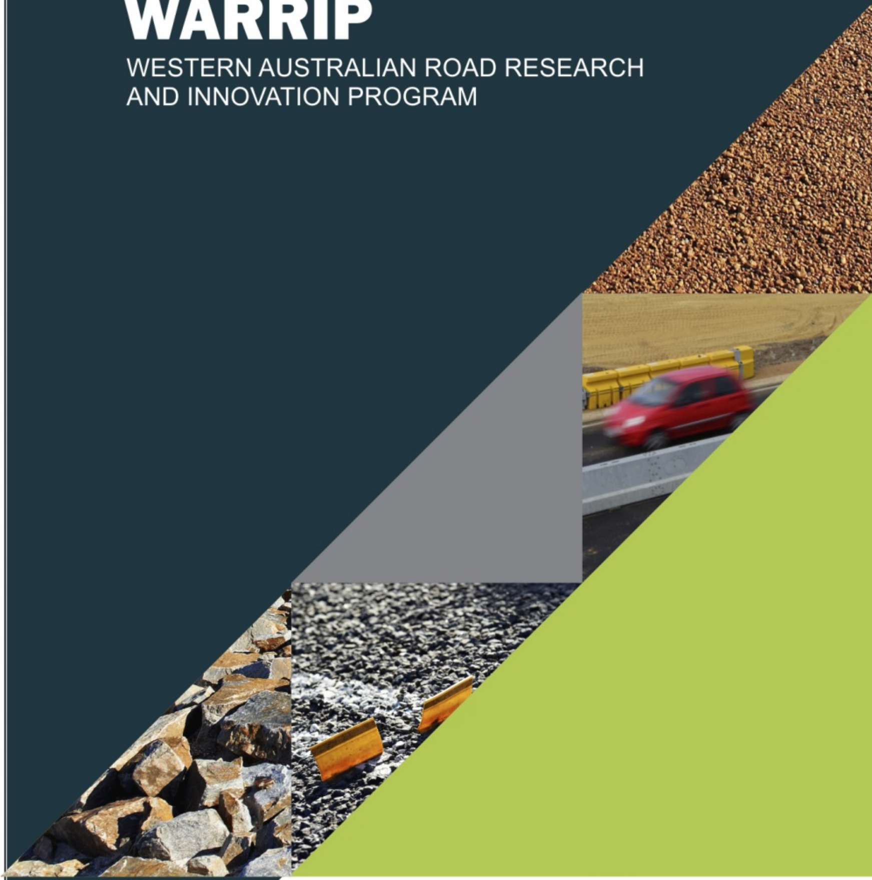

Key Findings & Recommendations

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Key Findings – Asphalt Mix Design

- Mix design parameters for Main Roads
  - Air voids 3.5 – 5.5% are less than other SRAs at 6% upper limit
  - Mandate use of hydrated lime (1.5%) and testing requirements (TSR) are in line with most of the SRAs except that Main Roads add a minimum wet strength (650 KPa).
- Main Roads investigation of the sites undergone stripping indicated that:
  - Sites having stripping issues were constructed using 2nd gen. asphalt mixes
  - Gateway Field Trials were constructed in 2015 using 2nd and 3rd gen. asphalt mixes
- The results of data analysis show clear improvement from 2nd to 3rd gen. asphalt mixes in terms of:
  - TSR
  - Permeability
  - Deformation resistance (WTT)

Key Findings – Asphalt Mix Design

- Aggregate type and mineralogy – more dominant factor than bitumen type.
- In Perth approved mixes are manufactured using granite – hydrophilic
  - Main Roads current technical documents do not provide any additional clause to address the risk of stripping due to granite aggregate
  - Two petrographic test results from Gateway Field Trials were provided, however more investigation is required to establish the threshold limits for hydrophilic minerals in Perth granite (e.g. quartz, k-feldspar). Which can be achieved through:
    - Lab testing on WA asphalt mixes constituent granitic and non-granitic aggregates (e.g. basalt, limestone).
    - Use of XRF to determine silica content, mineral assemblage and molecular structure.
    - Review of petrographic reports provided to Main Roads to meet the criteria of asphalt mix design approval process.

Key Findings – Asphalt Mix Placement

- Main Road specification is 3 – 7% in situ characteristic air voids
- US road agencies place asphalt at 8% in situ air voids to accommodate potential densification during first couple of years.
- Main Roads practice for in situ air voids content is more appropriate due to following reasons:
  - For higher range of limit (e.g. 7% or above) – poor compaction may result in air void content higher than the target upper limit leading to stripping
  - For lower range of the limit (e.g. 3 or blow) – over compaction may result in instability and deformation of the layer
- Compaction control is key to avoid deviation from the target compaction to inhibit moisture damage to the pavements.

Key Findings – Waterproof seal

- Main Roads specifies sprayed seal immediately below the wearing courses, and a tack coat of diluted emulsion on the prepared surface under all asphalt layers which is in line with other SRAs practice
- Other SRAs have additional requirements such as sprayed seal to waterproof granular base and double application rate of binder on joints.

Key Findings – Recommendations

- Consider laboratory tests to assess asphalt mix sensitivity to moisture. Identified tests are:
  - HWTT can be used as an indicator of stripping potential → USA road agencies.
  - Austroads → AGPT /T232 stripping potential of asphalt: TSR
  - TfNSW → T230 resistance to stripping of aggregates and binders in the presence of water (plate test or stripping test)
  - Screening test for aggregate based on best compatibility with binder for adhesion stability → SHRP's net adsorption test
  - Other possible tests on loose mix:
    - Static immersion test (AASHTO T182, ASTM D1664)
    - Boiling water test (ASTM D3625), total water immersion test (TWIT),
    - Ultrasonic water bath technique, rolling bottle method (BSEN 12697-11)
    - Saturated ageing tensile stiffness test (SATS)
    - Pneumatic adhesion tensile testing instrument (PATTI)

Key Findings - Recommendations

- Bailey method is well-established in the USA as a logical approach to aggregate packing analysis as a part of the asphalt mix design procedure.
  - Permeability plays a critical role in water flow through interconnected voids
- Main Roads to consider Bailey method in the mix design for investigating packing of the aggregate can help in achieving desired results

Future Research - Recommendations

- Continue to monitor the Gateway Trial Sections
- Continue detailed investigations on TLA or FDA pavements which have undergone stripping.
- Evaluate additional and/or alternative anti-stripping solutions for use with granite aggregates.
- Evaluate additional and/or alternative laboratory tests related to identifying moisture susceptibility.

Questions ?

Thank you

Find out more

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