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ANNUAL SUMMARY REPORT

P94 – Optimising the Use of Recycled Materials in Queensland for Unbound and Stabilised Products (2019/20 - Year 2)

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SUMMARY

In Queensland, the uptake of recycled material usage in unbound granular and stabilised pavements has been relatively limited since the 2010 publication of MRTS35 *Recycled Materials in Pavements.* This has been due to various reasons, including the perception that recycled materials are inferior to virgin materials and procurement barriers associated with having separate specifications for recycled and natural/quarried materials. The aim of this multi-year project is to facilitate the increased use of recycled materials in unbound pavements used by the Queensland Department of Transport and Main Roads (TMR).

This report summarises recycled material assessment undertaken through laboratory evaluation of several recycled pavement materials sourced from various suppliers in Queensland, and the update to TMR specifications. The key outcomes of this research are summarised as follows:

- Queensland suppliers producing RM001 and RM003 recycled materials consistently meet the characterisation and performance requirements of MRTS35 *Recycled Materials in Pavements.* These materials show improved performance compared to natural quarried materials and may therefore provide a suitable alternative.
- One recycled material mix incorporating up to 20% glass showed improved mix characterisation properties and performance compared to the same material with 0% glass.
- MRTS05 *Unbound Pavements* specification has been updated (July 2020 edition) to provide a single specification for the supply of natural, quarried and recycled materials based on the findings of this project.

Recommendations for the third year of this project includes:

- Disseminating research outcomes by conducting knowledge transfer workshops/webinars for industry and internal stakeholders to consult the specification changes.
- Consult with TMR districts for demonstration project opportunities and assist with the monitoring and surveillance of these projects to help address any issues where recycled materials are being considered.

ACKNOWLEDGEMENTS

The author would like to thank the recycled material suppliers and TMR for their contributions to this research through the supply of materials, data and relevant information.

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1 INTRODUCTION

1.1 BACKGROUND

The specification MRTS35 *Recycled Materials in Pavements* (TMR 2018a) was originally published in 2010, based on requirements defined in close consultation with the recycling industry in Queensland. These requirements were largely based on Victorian and New South Wales practices at the time with modifications to suit Queensland conditions and experience. Since this time, the uptake of recycled materials usage in unbound granular and stabilised pavements has been relatively limited due to a number of factors including:

- A perception that recycled materials are inferior to virgin materials.
- Limited technical knowledge regarding the allowable proportion of recycled materials and the long-term performance of these materials in certain pavement layers.
- In Queensland there is currently only a limited number of suppliers (compared to quarry sources) of these materials, located mainly in South-East Queensland, and
- Recycled materials are specified and procured in a different manner to quarry products, which can become an administrative barrier to their use.

In 2018, TMR endorsed a multi-year project under the National Asset Centre of Excellence (NACoE) research program with the aim to identify how the use of recycled materials can be optimised on TMR projects to achieve cost, sustainability and long-term performance benefits. The first year of the project, documented in *P94: Optimising the Use of Recycled Materials in Queensland for Unbound and Stabilised Products* – *Year 1 (2018/2019)* (Latter, Mohammadinia & Beecroft 2020) included a literature review of existing practice in Australia. The findings are summarised as follows:

- The use of recycled materials is widely accepted in unbound and stabilised pavement materials throughout Australia. While different agencies specify different limits, most of the publications identified have shown that in terms of performance; recycled materials are suitable for base and subbase applications.
- In general, state road agencies have strong alignment between specifications for traditional quarried materials and recycled materials.
- Recycled materials such as crushed concrete, crushed brick, reclaimed asphalt pavement and crushed glass have been widely used in Australia and may have scope for allowing increased percentages in Queensland pavements.
- Regarding environmental considerations, there is general alignment across Australia in the testing and threshold values allowed.

Recommendations for Year 2 of this project included sampling recycled materials from a number of suppliers in Queensland and undertaking classification and performance testing to determine compliance against specification limits. Performance testing using repeat load triaxial (RLT) and wheel tracker testing were undertaken to develop specification limits for recycled materials and assist in updating the current TMR specifications.

1.2 OBJECTIVE

The general objective of this project is to identify how the use of recycled materials can be optimised on TMR projects to achieve cost, sustainability and long-term performance benefits. This report outlines the second year of a multi-year project where the primary objective of Year 2 was to facilitate the increased use of recycled materials in unbound pavements by updating the specification based on the performance assessment of several recycled pavement materials sourced from various suppliers in Queensland.

1.3 METHODOLOGY

The approach undertaken is summarised as follows:

- Characterise the properties of two types of recycled material blends (RM001 and RM003) available in Queensland by conducting laboratory testing – Section 2.
- Assess the performance of RM001 and RM003 recycled material blends available in Queensland by undertaking tests that provide indicative measures of in situ performance – Section 3.
- Recommend updates to TMR specifications based on the results of laboratory testing – Section 4.
- Summarise key findings and recommendations for future years of research – Section 5.

2 MATERIAL CHARACTERISATION

An exploratory laboratory testing regime on RM001 materials sourced from four suppliers in Queensland and RM003 materials sourced from seven Queensland suppliers was undertaken to characterise the engineering properties and performance of these materials. However, it must be noted that only three samples of the RM003 materials were selected for full analyses and comparison to the RM001 materials. This included undertaking petrographic analysis and material characterisation testing.

2.1 PETROGRAPHIC ANALYSIS

Petrographic analysis of rocks allows identification of the type of rock based on its mineralogy and texture. The petrographic examination was conducted using a microscope, both in plane-polarised light (PPL) and cross-polarised light to describe textures (geometrical relationships among component crystals), crystallinity (degree of crystallisation), granularity (grain size), crystal shapes and the arrangement of crystals and mineral content. Thin sections of the samples were prepared to permit detailed examination in transmitted polarised light of random fragments. An approximate average composition of the aggregate expressed in volume percent and based on a brief count of 100 widely spaced points falling within sectioned fragments was determined following ASTM C295/ C295M–19 *Standard Guide for Petrographic Assessment of Aggregates for Concrete* and AS 2758.1 *Aggregates and Rock for Engineering Purposes Part 1: Concrete Aggregates*.

2.1.1 RM001 PETROGRAPHIC ANALYSIS

Table 2.1 presents the mineral composition of the samples sourced from the RM001 material suppliers in Queensland for both the coarse (>2.36 mm) and fine (<2.36 mm) fractions. This shows an approximate average composition of the supplied materials, expressed in volume percent, where each of the total proportions for each supplier shall sum to 100%. Generally, these minerals as classified into three categories, crushed rock aggregate which have fragmented from the recycled concrete aggregate as well as the sand components and hardened cement paste within the concrete fragments. For engineering purposes, the supplied samples may be summarised as consisting of a mixture of concrete fragments and liberated fragments of various compositions.

Table 2.1: RM001 mineral composition of the recycled material supplier samples

Description	Coarse fraction (>2.36 mm)				Fine fraction (<2.36 mm)			
	Supplier A	Supplier B	Supplier C	Supplier D	Supplier A	Supplier B	Supplier C	Supplier D
Crushed rock aggregate								
Olivine basalt	24%	14%	–	12%	–	–	–	–
Finely veined and recrystallized chert	11%	–	–	–	–	–	–	–
Slightly carbonaceous meta-siltstone	11%	–	–	–	–	–	–	–
Andesite	–	9%	–	–	–	–	–	–
Siliceous hornsfelsed phyllite	–	7%	6%	–	–	–	–	–
Chert/jasper	–	4%	–	–	–	–	–	–
Meta-greywacke	–	8%	15%	–	–	–	–	–
Vein quartz	–	–	7%	–	–	–	–	–
Granite	–	–	5%	–	–	–	–	–
Trachyte	–	–	4%	17%	–	–	–	–
Sand components (within concrete fragments)								
Quartz grains	9%	10%	12%	9%	24%	24%	19%	29%
Quartzite clasts	3%	6%	8%	–	8%	8%	10%	5%

Description	Coarse fraction (>2.36 mm)				Fine fraction (<2.36 mm)			
	Supplier A	Supplier B	Supplier C	Supplier D	Supplier A	Supplier B	Supplier C	Supplier D
Altered rhyolite clasts	10%	–	–	18%	1%	–	–	–
Weathered rhyolite	–	–	–	–	–	3%	–	–
Basalt	–	–	–	–	6%	–	–	–
Basalt clasts	–	4%	–	–	–	5%	3%	–
Feldspar	–	–	–	–	–	2%	–	–
Feldspar grains	4%	–	1%	2%	3%	–	4%	6%
Meta-greywacke clasts	1%	7%	3%	–	3%	3%	3%	–
Siltstone	–	–	–	–	1%	3%	–	–
Siltstone clasts	–	–	–	–	–	–	–	1%
Granite	–	–	–	–	5%	1%	–	–
Granite clasts	–	–	4%	–	–	–	7%	5%
Greenstone	–	–	–	–	1%	–	–	–
Greenstone clasts	–	2%	4%	–	–	1%	–	2%
Chert/jasper clasts	–	4%	–	–	–	–	–	–
Mica (free grain)	–	–	–	–	–	1%	–	–
Volcaniclastic sandstone clasts	–	–	4%	–	–	–	5%	–
Chert clasts	–	–	2%	–	–	–	4%	6%
Vein quartz	–	–	–	–	–	–	3%	1%
Trachyte	–	–	–	–	–	–	3%	–
Trachyte clasts	–	–	–	22%	–	–	–	8%
Calcite grains	–	–	–	–	–	–	1%	–
Argillized clasts	–	–	–	–	–	–	–	1%
Liberated pyroxene	–	–	–	–	–	–	–	1%
Shell fragments	<1%	<1%	<1%	<1%	<1%	1%	<1%	<1%
Hardened cement paste (within concrete fragments)								
Normal hardened cement paste blended with fly ash	16%	24%	17%	18%	29%	25%	23%	29%
Ettringite-effected cement paste	3%	–	1%	–	9%	14%	6%	–
Carbonated cement paste	6%	–	6%	–	9%	9%	5%	6%
Vesicles	2%	1%	1%	2%	1%	<1%	<1%	<1%

2.1.2 RM003 PETROGRAPHIC ANALYSIS

The mineral composition of the samples sourced from the RM003 material suppliers in Queensland for both the coarse (>2.36 mm) and fine (<2.36 mm) fractions is summarised in Table 2.2. Similar to the RM001 petrographic analysis, the supplied RM003 materials may be summarised as consisting of a mixture of concrete fragments and liberated fine fragments of various compositions.

Table 2.2: RM003 mineral composition of the recycled material supplier samples

Description	Coarse fraction (>2.36 mm)			Fine fraction (<2.36 mm)		
	Supplier F	Supplier G (0% glass)	Supplier G (20% glass)	Supplier F	Supplier G (0% glass)	Supplier G (20% glass)
Crushed rock aggregate						
Basalt	–	–	16%	–	–	–
Andesite	6%	–	–	–	–	–

Description	Coarse fraction (>2.36 mm)			Fine fraction (<2.36 mm)		
	Supplier F	Supplier G (0% glass)	Supplier G (20% glass)	Supplier F	Supplier G (0% glass)	Supplier G (20% glass)
Siliceous hornsfelsed phyllite	4%	23%	4%	–	–	–
Chert	–	–	4%	–	–	–
Chert/jasper	1%	–	–	–	–	–
Meta-greywacke	–	10%	<1%	–	–	–
Quartzite	–	17%	9%	–	–	–
Hematite pelite	–	4%	–	–	–	–
Greenstone	–	–	10%	–	–	–
Acid igneous	–	–	10%	–	–	–
Volcaniclastic siltstone	–	–	15%	–	–	–
Granite	–	4%	–	–	–	–
Sand components (within concrete fragments)						
Quartz grains	26%	10%	6%	24%	23%	13%
Quartzite clasts	6%	3%	2%	6%	4%	5%
Weathered rhyolite	–	–	–	7%	–	–
Basalt clasts	4%	3%	<1%	<1%	2%	3%
Feldspar	1%	–	–	3%	–	–
Feldspar grains	–	1%	1%		2%	4%
Meta-greywacke clasts	9%	1%	<1%	5%	–	3%
Siltstone	–	–	–	2%	–	
Meta-siltstone	–	–	–	–	3%	2%
Granite	–	–	–	4%	–	
Granite clasts	–	<1%	1%	–	3%	1%
Greenstone	–	–	–	–	–	–
Greenstone clasts	1%	3%	<1%	4%	4%	3%
Chert clasts	–	–	<1%	–	–	–
Chert/jasper clasts	3%	–	–	–	–	–
Limestone/calcite	–	–	–	6%	–	–
Volcaniclastic sandstone	–	–	–	–	5%	4%
Chert clasts	–	<1	–	–	3%	2%
Vein quartz	–	–	–	–	1%	2%
Siliceous hornsfelsed phyllite	6%	–	–	–		
Trachyte	–	–	–	–	<1%	<1%
Calcite grains	–	–	–	–	8%	<1%
Acid volcanic/tuffaceous	–	–	–	–	3%	4%
Calcite	–	–	2%	–	–	–
Plant material	–	–	1%	1%	–	–
Shell fragments	<1	<1	<1	<1	<1	<1
Hardened cement paste (within concrete fragments)						
Normal hardened cement paste blended with fly ash	13%	13%	14%	12%	18%	12%

Description	Coarse fraction (>2.36 mm)			Fine fraction (<2.36 mm)		
	Supplier F	Supplier G (0% glass)	Supplier G (20% glass)	Supplier F	Supplier G (0% glass)	Supplier G (20% glass)
Carbonated cement paste	15%	6%	3%	26%	10%	9%
Vesicles	5%	2%	2%	<1	<1	<1
Grain coating						
Asphalt	–	–	–	–	4%	1%
Clay coating	–	–	–	–	5%	6%
Misc.						
Free silica content	40%	40%	30%	34%	34%	25%
Manufactured glass fragment	–	–	–	–	–	26%

2.2 MATERIAL CHARACTERISATION

2.2.1 RM001 MATERIALS

The material gradation was undertaken in accordance with TMR test method Q103A *Particle Distribution of a Soil – Wet Sieving* (TMR 2020a). The particle size distribution (PSD) results for each of the recycled material samples tested by the TMR laboratory at Bulwer Island, Qld are summarised in Table 2.3 and depicted in Figure 2.1. This generally shows that the material conforms to the MRTS35 specification grading envelope except for Supplier B on the 2.36 mm sieve, showing minor non-conformance (NC) and the 0.075 mm sieve for all suppliers, indicating a lower content of fines than required for all suppliers.

Table 2.3: RM001 PSD results summary

Sieve size (mm)	Supplier				MRTS35 limits*	
	A	B	C	D	Lower	Upper
26.5	100	100	100	100	100	100
19	97	98	98	95	95	100
13.2	83	86	82	83	78	92
9.5	70	71	67	72	63	83
4.75	51	56	45	49	44	64
2.36	37	50	35	38	30	48
1.18	26	36	26	31	–	–
0.6	18	23	20	24	–	–
0.425	15	19	17	20	13	21
0.3	11	13	13	16	–	–
0.15	5.1	6	6.3	6.9	–	–
0.075	2.9	2.6	4.1	4.4	5	11

**Specification limits are given based on those specified in MRTS35 (TMR 2018a) for RM001 materials.*

Figure 2.1: RM001 gradation curve

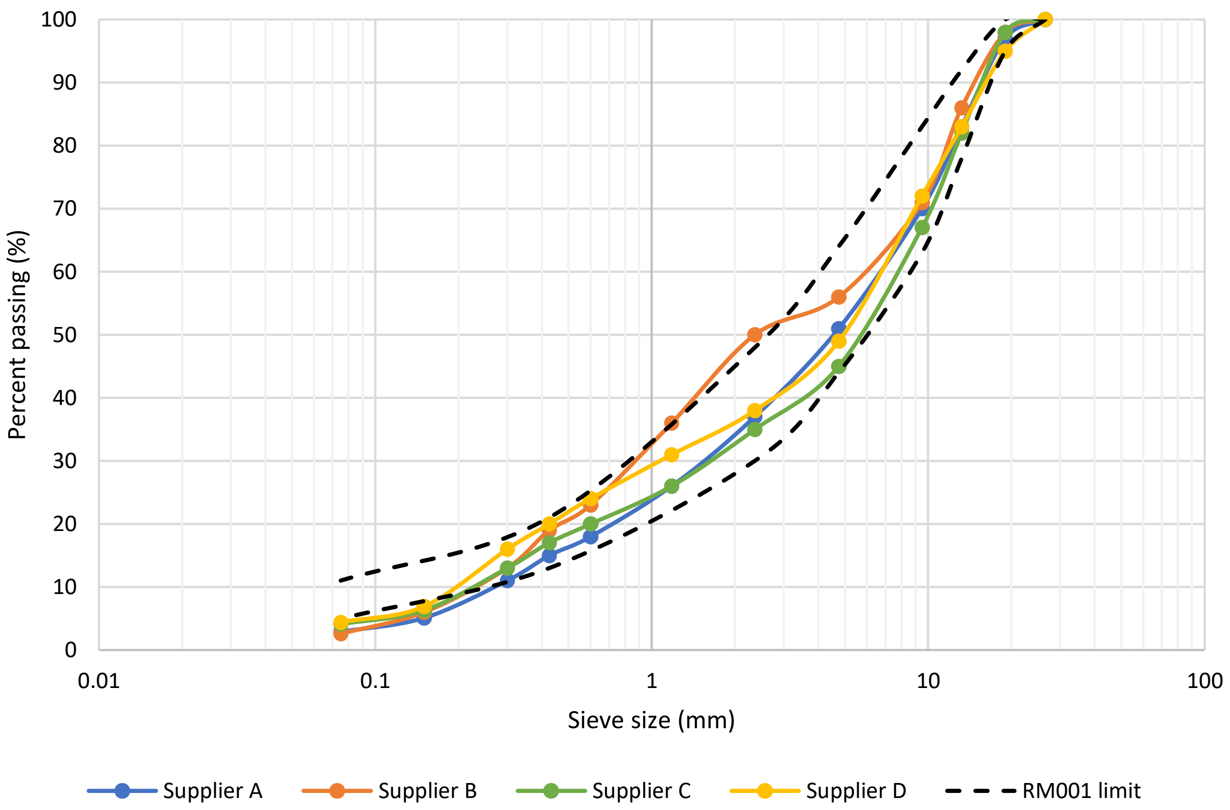


Table 2.4 presents the results and property limits for each of the supplier sourced RM001 materials in accordance with MRTS35. This shows that the coarse component of all tested materials complied with the TMR requirements, although the wet/dry strength variation for each material was close the 35% limit.

In the fine component of the RM001 materials, Supplier A and Supplier B exceeded the MRTS35 liquid limit (LL) of 35%. As noted in Griffin, Rice & Andrews (2016) it is common for porous aggregates such as those derived primarily from crushed recycled concrete to have a LL significantly in excess of 25% but display a plasticity index (PI) within an acceptable range. This is demonstrated by both the linear shrinkage (LS) conforming for all recycled materials tested as well as the PI of all materials below the now superseded MRTS05 *Unbound Pavements* (TMR 2018b) limit of 6% for Type 2.1 materials. Notably, the coarse component degradation factors for all suppliers is much lower than 40-50 degradation factor that is specified for natural gravel and quarried materials, varying with material group.

MRTS05 (TMR 2020b) notes that a higher fines ratio can lead to a reduction in stability and strength while a lower ratio increases permeability, poor surface and reduces surface stability for unbound pavement material performance.

Table 2.4: RM001 property results

Test	Test method	Supplier				MRTS35 limits*
		A	B	C	D	
Coarse component (> 0.425 mm)						
Wet strength (kN)	Q205ABC	97	101	111	93	≥ 85
Wet/dry strength variation (%)	Q205ABC	32	32	31	34	≤ 35
Degradation factor	Q208B	7	9	3	5	–
Flakiness index (%)	Q201	10	4	8	10	≤ 35
Apparent particle density (t/m^3)	Q214B	2.69	2.64	2.68	2.63	–

Test	Test method	Supplier				MRTS35 limits*
		A	B	C	D	
Particle density dry (t/m^3)	Q214B	2.27	2.33	2.33	2.27	–
Particle density SSD (t/m^3)	Q214B	2.43	2.45	2.46	2.4	–
Water absorption (%)	Q214B	6.7	5	5.5	6	–
Fine component (< 0.425 mm)						
Liquid limit (%)	Q104A	37.8	39.2	33.2	34.0	≤ 35
Plastic limit (%)	Q105	35.8	36.6	30.6	30.0	–
Plasticity index (%)	Q105	2.0	2.6	2.6	4.0	–
Linear shrinkage (%)	Q106	1.6	1.6	1.4	3.0	≤ 3.5
Weighted linear shrinkage	Q106	24	30	23	59	≤ 85
Degradation factor	AS 1141.25.3	–	–	–	–	–
Fines ratio	Q103A	0.19	0.14	0.24	0.21	–
Apparent particle density (t/m^3)	Q214A	2.61	2.59	2.62	2.58	–
Particle density dry (t/m^3)	Q214A	2.08	2.14	2.23	2.12	–
Particle density SSD (t/m^3)	Q214A	2.29	2.32	2.38	2.3	–
Water absorption (%)	Q214A	9.7	8.1	6.8	8.5	–

**Specification limits are given based on those specified in MRTS35 (TMR 2018a) for RM001 materials.*

The maximum dry density (MDD), optimum moisture content (OMC) and California Bearing Ratio (CBR) tests were conducted on each of the recycled material samples using both standard and modified compaction. Testing also included assessment of the water absorption, degradation factor and unconfined compressive strength (UCS). The results are presented in Table 2.5.

The results show that the variations between CBR values determined using standard and modified effort are significant, with greater MDD and lower OMC determined when applying modified effort, the stability increases with density. Additionally, the OMC for all samples is relatively high, where Supplier A and Supplier B show in excess of 15% indicating the material has a propensity for water. Notably, the standard MDD (1.80-1.91 t/m^3) and modified MDD (1.89-1.99 t/m^3) are comparatively lower than typical quarried material (approximately 2.1 t/m^3 or greater). This is an advantage because for construction projects there would be less tonnage required to build the same pavement, thus leading to cost savings.

It can also be observed in Table 2.5 that the water absorption values for both the coarse and fine fractions are relatively high and may indicate that similar to the LL results, recycled materials comprised of porous material such as crushed recycled concrete has a propensity for water absorption. The UCS results for all RM001 materials easily conform to the MRTS05 requirements of the 0.7 MPa limit indicating that the materials will not act as a stabilised material.

Table 2.5: RM001 MDD, OMC, CBR, water absorption and UCS test results

Test	Test method	Supplier				MRTS35 limits*
		A	B	C	D	
Standard MDD (t/m^3)	Q142A	1.80	1.81	1.91	1.88	–
Standard OMC (%)	Q102A	16.5	15.5	14.0	14.0	–
Modified MDD (t/m^3)	Q142B	1.89	1.90	1.99	1.95	–
Modified OMC (%)	Q102B	14.0	13.0	11.5	12.0	–
Standard CBR (%)	Q113A	130	100	60	90	80

Test	Test method	Supplier				MRTS35 limits*
		A	B	C	D	
Modified CBR (%)	Q113B	280	220	210	180	–
Water absorption – fine (%)	Q214A	9.7	8.1	6.8	8.5	–
Water absorption – coarse (%)	Q214B	6.7	5.0	5.5	6.0	–
UCS (MPa)	Q115	0.2	0.2	0.1	0.3	≤ 0.7

**Specification limits are given based on those specified in MRTS35 (TMR 2018a) for RM001 materials.*

The foreign material test results for each of the RM001 materials tested are summarised in Table 2.6. This shows the material was generally free of foreign materials with the exception of asphalt in three of the four suppliers.

Table 2.6: RM001 foreign material test results

Constituent of foreign material	Test method	Supplier				MRTS35 specification limits (% by mass) *
		A	B	C	D	
Brick	Q477	0.2	0.6	0.5	0.6	≤ 1
Metal, ceramics and slag (other than blast furnace slag)		0.0	0.0	0.0	0.0	≤ 3
Plaster, clay lumps and other friable material		0.0	0.2	0.0	0.1	≤ 1
Rubber, plastic, bitumen not part of asphalt, paper, cloth, paint, wood and other vegetable matter		0.0	0.0	0.0	0.2	≤ 0.2
Asphalt		0.5	2.4	2.1	2.2	≤ 1

**Specification limits are given based on those specified in MRTS35 (TMR 2018a) for RM001 materials.*

2.2.2 RM003 MATERIALS

The PSD data results for each of the RM003 samples tested by the TMR laboratory on Bulwer Island, Qld are summarised in Table 2.7 and depicted in Figure 2.2. This shows complete compliance to the TMR RM003 specification envelope. It is noted that in Figure 2.2 the material from Supplier G (20% glass) leaves the specification envelope at the interpolated 1.18 mm and 0.60 mm sieve, however, these two sieve sizes do not currently have a specified percentage passing range and the next sieve, the 0.425 mm shows compliance, so from a specification perspective this mix would be considered conforming.

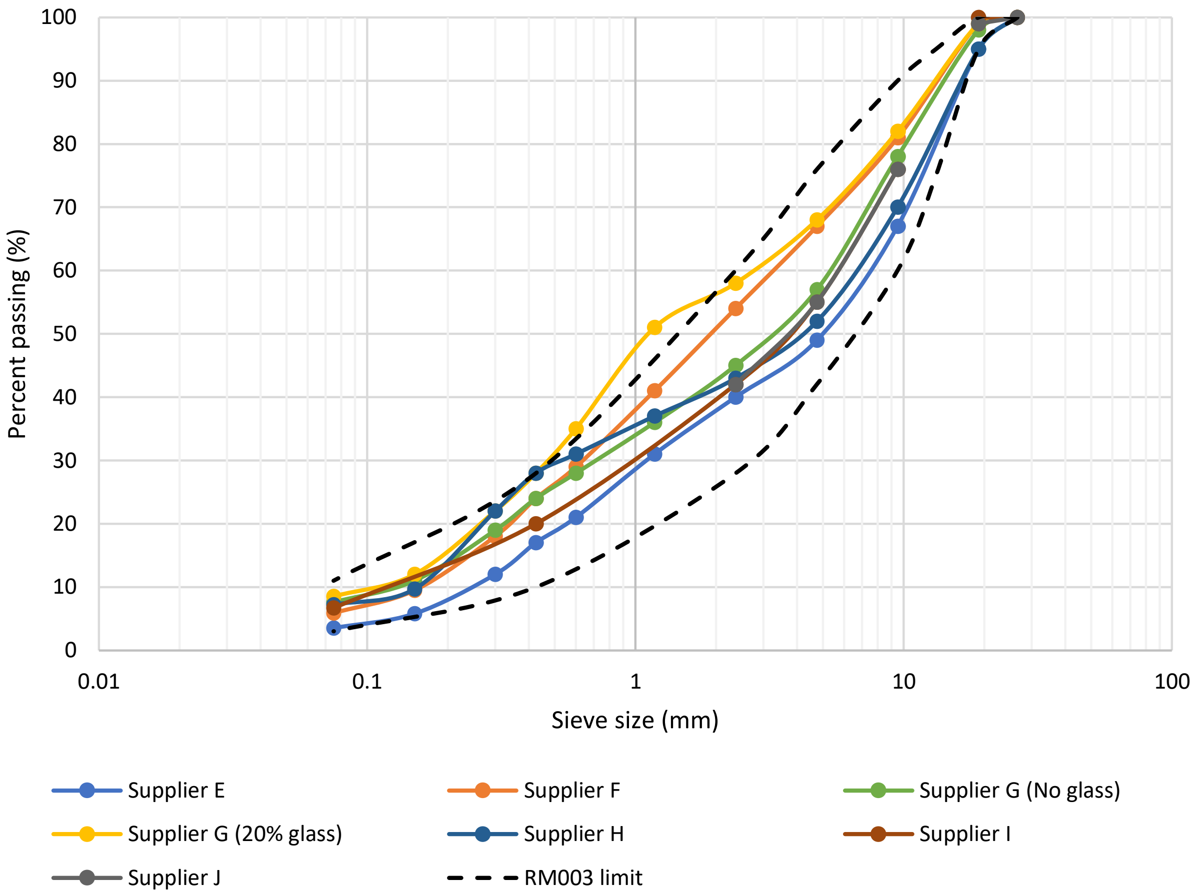
Table 2.7: RM003 PSD testing summary

Sieve size (mm)	Supplier							MRTS35 limits*	
	E	F	G (0% glass)	G (20% glass)	H	I	J	Lower	Upper
26.5	100	100	100	100	100	100	100	100	100
19	95	99	98	99	95	100	99	95	100
13.2	–	–	–	–	–	–	–	75	95
9.5	67	81	78	82	70	76	76	60	90
4.75	49	67	57	68	52	55	55	42	76
2.36	40	54	45	58	43	42	42	28	60
1.18	31	41	36	51	37	–	–	–	–
0.6	21	29	28	35	31	–	–	–	–
0.425	17	24	24	28	28	20	19	10	28

Sieve size (mm)	Supplier							MRTS35 limits*	
	E	F	G (0% glass)	G (20% glass)	H	I	J	Lower	Upper
0.3	12	18	19	22	22	–	–	–	–
0.15	5.8	9.5	11	12	9.7	–	–	–	–
0.075	3.5	5.9	7.6	8.5	7.2	6.7	5.3	3	11

**Specification limits are given based on those specified in MRTS35 (TMR 2018a) for RM003 materials.*

Figure 2.2: RM003 gradation curve



The property limits for each of the RM003 test results are summarised in Table 2.8. These results show that the RM003 materials conformed to the MRTS35 LS specification limit of 4.5% max. Similar to the RM001 materials, the LLs for each material is high although notably, are generally lower than the RM001 LLs. The coarse component degradation factors are also relatively low, similar to the RM001 materials.

Table 2.8: RM003 property limit results

Test	Test method	Supplier							MRTS35 limits*
		E	F	G (0% glass)	G (20% glass)	H	I	J	
Coarse component (> 0.425 mm)									
Wet strength (kN)	Q205ABC	–	87	98	108	–	–	–	≥ 70
Wet/dry strength variation (%)	Q205ABC	–	31	38	28	–	–	–	≤ 45
Degradation factor	Q208B	–	8	6	8	–	–	–	–

Test	Test method	Supplier							MRTS35 limits*
		E	F	G (0% glass)	G (20% glass)	H	I	J	
Flakiness index (%)	Q201	–	8	13	10	–	–	–	≤ 40
Apparent particle density (t/m³)	Q214B	–	2.63	2.66	2.66	–	–	–	–
Particle density dry (t/m³)	Q214B	–	2.29	2.29	2.30	–	–	–	–
Particle density SSD (t/m³)	Q214B	–	2.42	2.43	2.43	–	–	–	–
Water absorption (%)	Q214B	–	5.7	6.1	6.0	–	–	–	–
Fines component (< 0.425 mm)									
Liquid limit (%)	Q104A	34.6	33.4	31.4	30.4	31.0	32.2	32.8	≤ 35
Plastic limit (%)	Q105	30.6	29.8	25.2	25.8	27.6	26.2	27.8	–
Plasticity index (%)	Q105	4.0	3.6	6.2	4.6	3.4	6.0	5.0	–
Linear shrinkage (%)	Q106	1.6	1.4	2.6	2.2	2.2	1.6	2.0	≤ 4.5
Weighted linear shrinkage	Q106	27	33	62	63	61	32	38	≤ 110
Degradation factor	AS 1141.25.3	–	39	–	25	–	–	–	–
Fines ratio	Q103A	0.21	0.25	0.32	0.3	0.26	0.34	0.28	
Apparent particle density (t/m³)	Q214A	–	2.62	2.62	2.60	–	–	–	–
Particle density dry (t/m³)	Q214A	–	2.19	2.19	2.32	–	–	–	–
Particle density SSD (t/m³)	Q214A	–	2.35	2.35	2.43	–	–	–	–
Water absorption (%)	Q214A	–	7.50	7.50	4.06	–	–	–	–

**Specification limits are given based on those specified in MRTS35 (TMR 2018a) for RM003 materials.*

Table 2.9 presents the RM003 test results for MDD, OMC and CBR using both standard and modified compaction where applicable, as well as the water absorption and UCS results. The results show that similar MDD and OMC values to the RM001 materials for both standard and modified compaction. Minimum CBR requirements at standard compaction were generally met, except for the material from Supplier G (0% glass), with a value of 35% although the 20% glass sample achieved a CBR of 60%. It is possible that this difference is due in part to the accuracy of the CBR test method. Notably, the CBR value measured when the samples were prepared using modified compaction were significantly increased for all three suppliers tested, where the 0% glass mix improved to a greater value than the 20% glass mix although the standard compaction value was lower. However, as this test was only undertaken on one sample this result may have been affected by laboratory variability.

The water absorption values for both the coarse and fine fractions indicate that similar to the RM001 results, the material may have a propensity for water absorption. The UCS results from all suppliers easily conform to the MRTS35 requirements of the 0.7 MPa limit indicating that the materials will not act as a stabilised material.

Table 2.9: RM003 MDD, OMC, CBR, water absorption and UCS test results

Test	Test method	Supplier							MRTS35 limits*
		E	F	G (0% glass)	G (20% glass)	H	I	J	
Standard MDD (t/m³)	Q142A	1.79	1.78	1.92	1.92	1.83	1.84	1.78	–
Standard OMC (%)	Q102A	13.5	15.0	13.5	13.0	15.0	14.5	18.0	–
Modified MDD (t/m³)	Q142B	–	1.91	2.01	2.01	–	–	–	–

Test	Test method	Supplier							MRTS35 limits*
		E	F	G (0% glass)	G (20% glass)	H	I	J	
Modified OMC (%)	Q102B	–	13.0	11.0	10.5	–	–	–	–
Standard CBR (%)	Q113A	90	60	35	60	60	60	80	≥ 45
Modified CBR (%)	Q113B	–	130	190	160	–	–	–	–
Water absorption – fine (%)	Q214A	–	7.5	7.5	4.6	–	–	–	–
Water absorption – coarse (%)	Q214B	–	5.7	6.1	6.0	–	–	–	–
UCS (MPa)	Q115	0.2	0.2	0.2	0.1	0.2	0.2	0.0	≤ 0.7

**Specification limits are given based on those specified in MRTS35 (TMR 2018a) for RM003 materials.*

The Table 2.10 summarises the results for each of the RM003 materials tested, showing that the material conformed to the MRTS35 specification limits. It is important to note that the Supplier F material contained a large proportion of brick (26.9%) although not a specified limit for RM003 materials. When sourcing the materials, the project team requested suppliers to maximise the amount of brick that was incorporated so help assess its impact at higher levels, however from visual inspection of the bulk sample it is apparent that this result is due to sampling from the bulk sample.

Table 2.10: RM003 foreign material test results

Constituent of foreign material	Test method	Supplier							MRTS35 limits (% by mass)*
		E	F	G (0% glass)	G (20% glass)	H	I	J	
Brick	Q477	0	26.9	0.1	2.1	0	1.1	1.1	–
Metal, ceramics and slag (other than blast furnace slag)		0	0.1	0.3	0.1	0	0	1.3	≤ 3
Plaster, clay lumps and other friable material		0	0	0	0	0	0.8	0.4	≤ 1
Rubber, plastic, bitumen not part of asphalt, paper, cloth, paint, wood and other vegetable matter		0	0	0.1	0	0.1	0.1	0.1	≤ 0.2
Asphalt		0	0	0	0	0	0	0.2	–

**Specification limits are given based on those specified in MRTS35 (TMR 2018a) for RM003 materials.*

3 PERFORMANCE ASSESSMENT

An exploratory laboratory testing regime was undertaken to assess the performance of RM001 and RM003 materials. Testing was undertaken on supplier sourced samples from Queensland and supplemented with additional data provided by TMR, discussed in the relevant sections. Performance evaluation was undertaken through RLT testing, wheel tracker testing and extra large wheel tracking (XL-WT).

3.1 REPEAT-LOAD TRIAXIAL

The RLT test provides an indication of the stiffness and rutting susceptibility of pavement materials, indicated by resilient modulus and permanent deformation. This method is typically used as it closely replicates the in situ loading conditions applied to pavement materials in which a constant axial stress is repeatedly applied to the surface of the cylindrical specimen conditioned under a constant confining pressure. RLT testing was conducted in accordance with TMR test method Q137 *Permanent Deformation and Resilient Modulus of Granular Unbound Materials* (TMR 2020a). The specimens were prepared at two densities given by the MDD obtained either under standard or modified compactive effort. For each density, the specimens were also tested at a different degree of saturation (DOS) to assess the sensitivity to moisture, prepared by compacting at the target moisture contents.

The RLT results are presented and discussed for each recycled material supplier in the following sections.

3.1.1 RM001 RLT RESULTS

Supplier A

RLT testing was conducted on material sourced from Supplier A at standard and modified MDD as summarised in Table 3.1. The axial permanent strain measured for each loading cycle was plotted relative to the target DOS for the material sampled from Supplier A prepared at both standard and modified MDD is compared to the TMR assessment criteria in Figure 3.1. This shows that at 65% DOS and 70% DOS the standard compacted material sourced from Supplier A continues to perform below the 4.0% strain limit up to 50 000 cycles but exceeds this at 100 000 cycles. However, at 75% DOS the material shows exceedance of the maximum strain after 50 000 cycles while the standard compacted material at 80% DOS exceeded the 4.0% after only 10 000 cycles. Notably, when compacted at the modified MDD, the materials tested at 70% DOS and 80% DOS did not exceed a permanent strain of 1.0%, indicating that this material will perform significantly better if compacted at a higher MDD using modified effort.

The resilient modulus for each loading cycle plotted relative to the target DOS level for the Supplier A material prepared at standard and modified MDD is presented in Figure 3.2. This shows the initial modulus value, as well as the change in stiffness with subsequent load cycles for the different moisture conditions. Although TMR does not specify criteria for the resilient modulus determined using the RLT test, high resilient moduli at the design in situ moisture content is preferred. Figure 3.2 shows that for the samples prepared at standard MDD, post-conditioning (after 1000 cycles) the resilient modulus decreases at all DOS levels, where 70% DOS shows the highest resilient modulus of 350 MPa, falling to approximately 220 MPa at 100 000 cycles. Notably, the samples prepared at modified MDD show comparatively higher initial resilient moduli of up to 390 MPa which continue to increase post-conditioning to approximately 530 MPa at 70% DOS.

Table 3.1: Supplier A RLT testing conditions

Compaction effort	Target dry density (t/m^3)	Target moisture content (%)	Target DOS (%)	Target percentage of OMC (%)
Standard	1.80	11.8	65	72
	1.80	12.7	70	77
	1.80	13.6	75	82
	1.80	14.5	80	88

Compaction effort	Target dry density (t/m³)	Target moisture content (%)	Target DOS (%)	Target percentage of OMC (%)
Modified	1.89	10.8	70	77
	1.89	12.4	80	89

Figure 3.1: Supplier A permanent strain RLT results

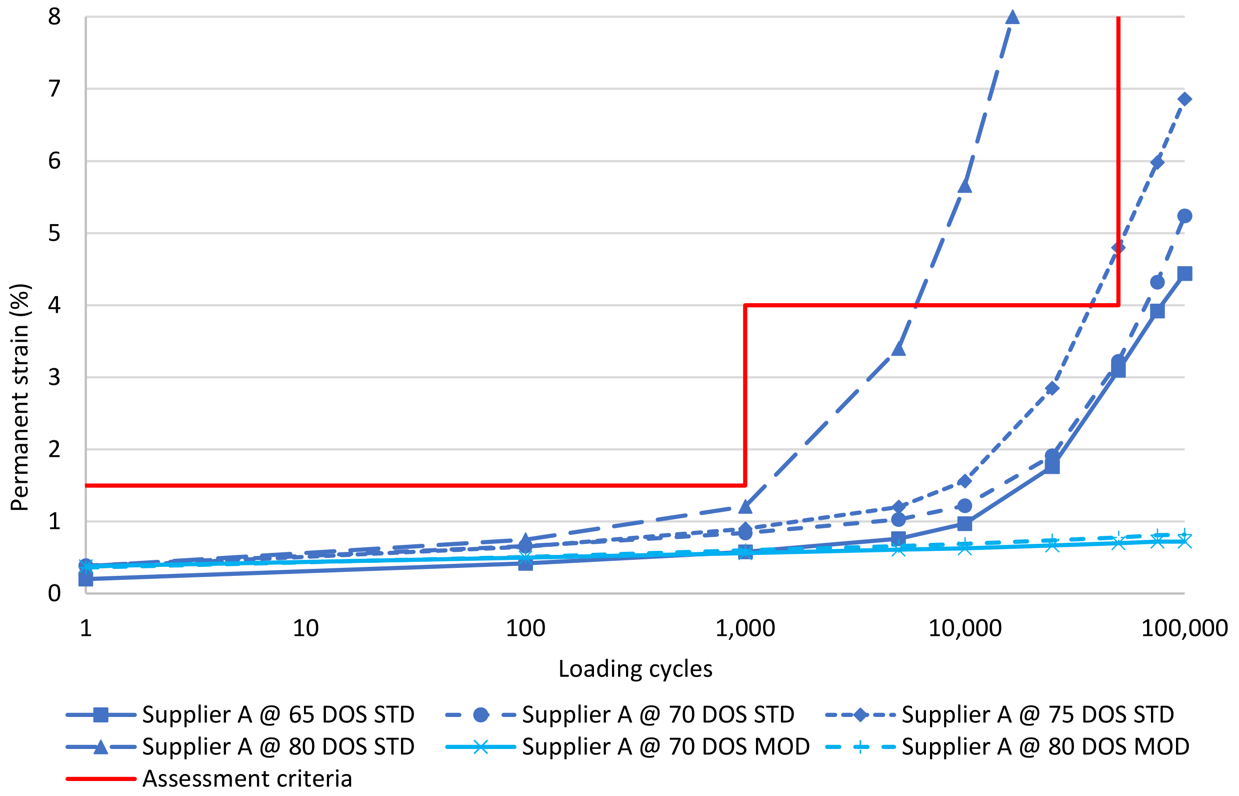
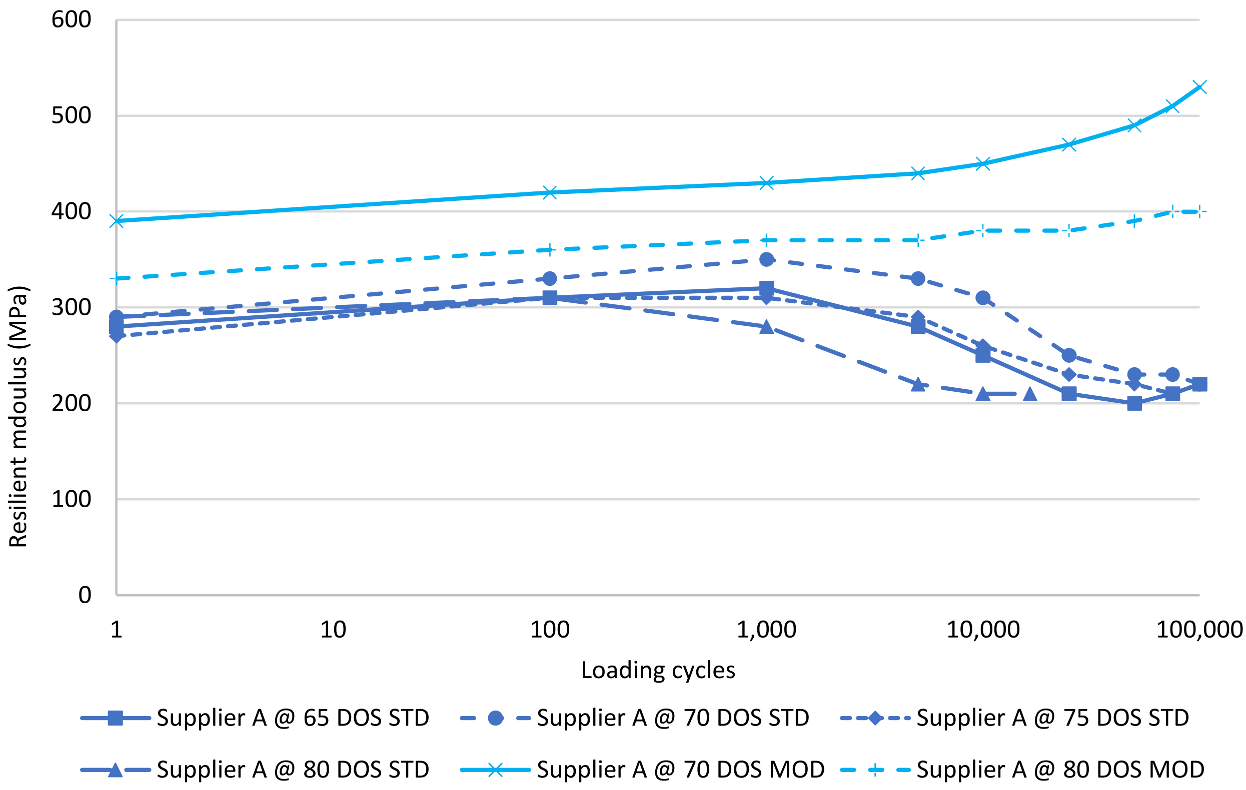


Figure 3.2: Supplier A resilient modulus RLT results



Supplier B

The Supplier B RLT permanent strain results tested at both standard and modified MDD using the test conditions summarised in Table 3.2 are presented in Figure 3.3. This shows that up to 80% DOS the standard compacted material from Supplier B was compliant in accordance with the TMR assessment criteria up to 50 000 cycles with a permanent strain of 3.9%. Similar to the material from Supplier A, when prepared at the modified MDD, the material from Supplier B did not exceed a permanent strain of 1.0%.

The resilient modulus results for the samples sourced from Supplier B prepared at standard and modified MDD are shown in Figure 3.4. Similar to the Supplier A results, this shows that the samples prepared at standard MDD, the resilient modulus decreases at all DOS levels post-conditioning with the exception of the sample tested at 65% DOS. The initial moduli of the standard MDD samples range from 280-310 MPa, whereas the moduli at 100 000 cycles ranges from 230-280 MPa, indicating relatively small changes due to loading. Notably, the samples prepared at modified MDD show comparatively higher resilient moduli ranging from 360-860 MPa at 70% DOS and 380-860 MPa at 80% DOS.

Table 3.2: Supplier B RLT testing conditions

Compaction effort	Target dry density (t/m^3)	Target moisture content (%)	Target DOS (%)	Target percentage of OMC (%)
Standard	1.81	11.3	65	73
	1.81	12.2	70	79
	1.81	13.0	75	84
	1.81	13.9	80	90
Modified	1.90	10.3	70	79
	1.90	11.8	80	91

Figure 3.3: Supplier B permanent strain RLT results

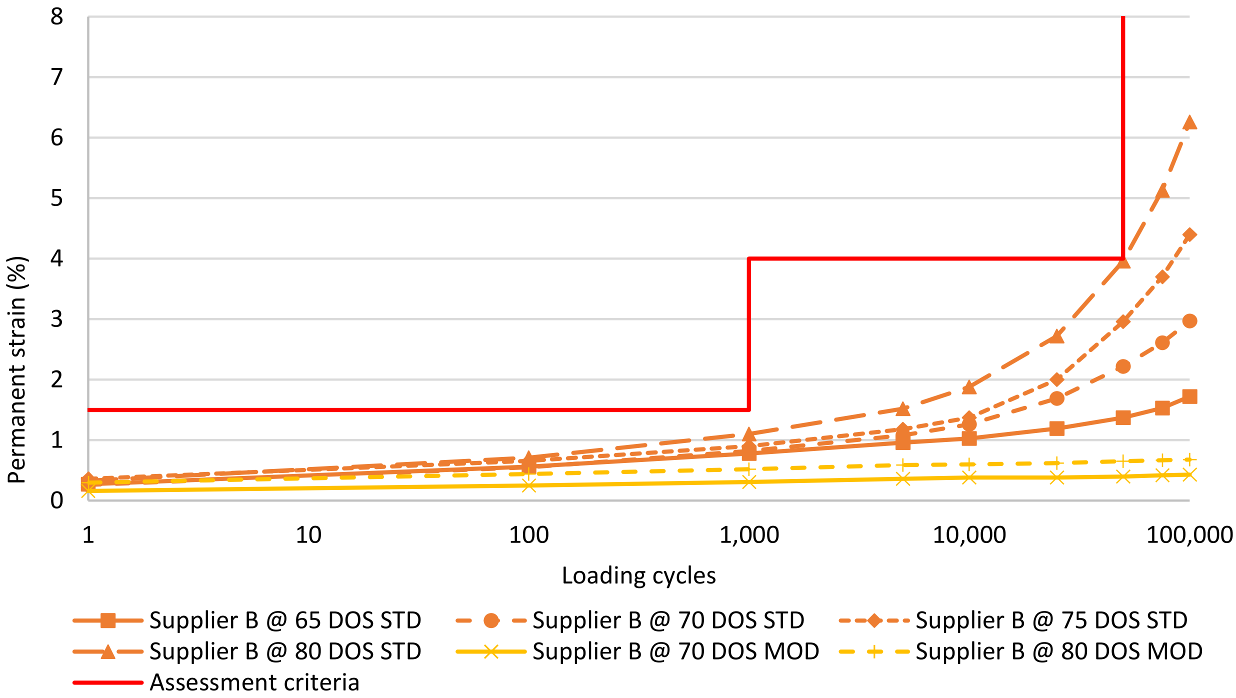
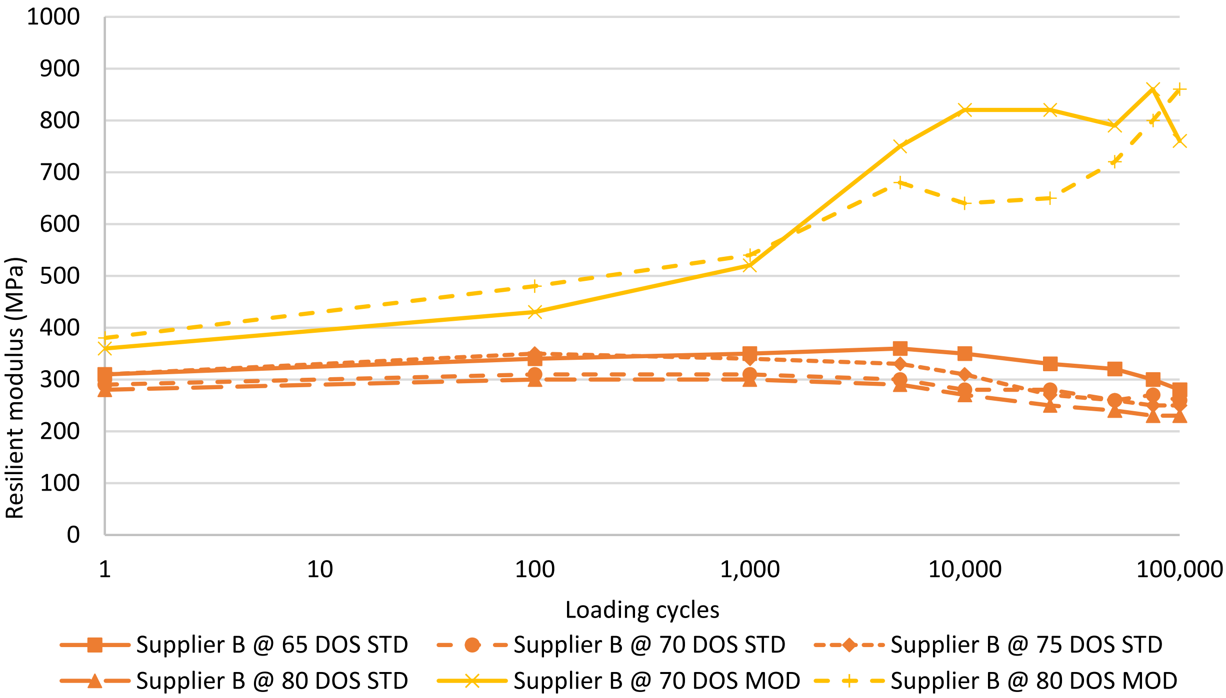


Figure 3.4: Supplier B resilient modulus RLT results



Supplier C

Table 3.3 summarises the Supplier C RLT testing conditions while Figure 3.5 depicts the permanent strain against loading cycle relative to the target DOS for each sample tested from Supplier C using both standard and modified MDD. The results show that for standard compaction, at 65% DOS and 70% DOS the material conforms to the TMR assessment criteria up to 100 000 cycles but exceeds the 4.0% permanent strain limit at 50 000 cycles for both 75% DOS and 80% DOS. The specimens prepared at modified MDD, testing at 70% DOS and 80% DOS shows approximately equal performance, not exceeding 1.0% permanent strain up to 100 000 cycles.

Figure 3.6 shows the resilient modulus results from the Supplier C samples prepared at standard and modified MDD. The samples prepared at standard MDD show similar initial resilient moduli (250-300 MPa) and to moduli after 100 000 cycles (270-320 MPa) where it is notable that the 70% DOS and 80% DOS samples both finished testing at approximately 320 MPa. Comparatively, the samples prepared at modified MDD show higher resilient moduli ranging from 330-400 MPa at 70% DOS and 380-460 MPa at 80% DOS, showing lesser improvements than observed between the standard and modified MDD samples than Supplier A and Supplier B.

Table 3.3: Supplier C RLT testing conditions

Compaction effort	Target dry density (t/m^3)	Target moisture content (%)	Target DOS (%)	Target percentage of OMC (%)
Standard	1.91	9.5	65	68
	1.91	10.2	70	73
	1.91	11.0	75	79
	1.91	11.7	80	84
Modified	1.99	8.8	70	77
	1.99	10.0	80	87

Figure 3.5: Supplier C permanent strain RLT results

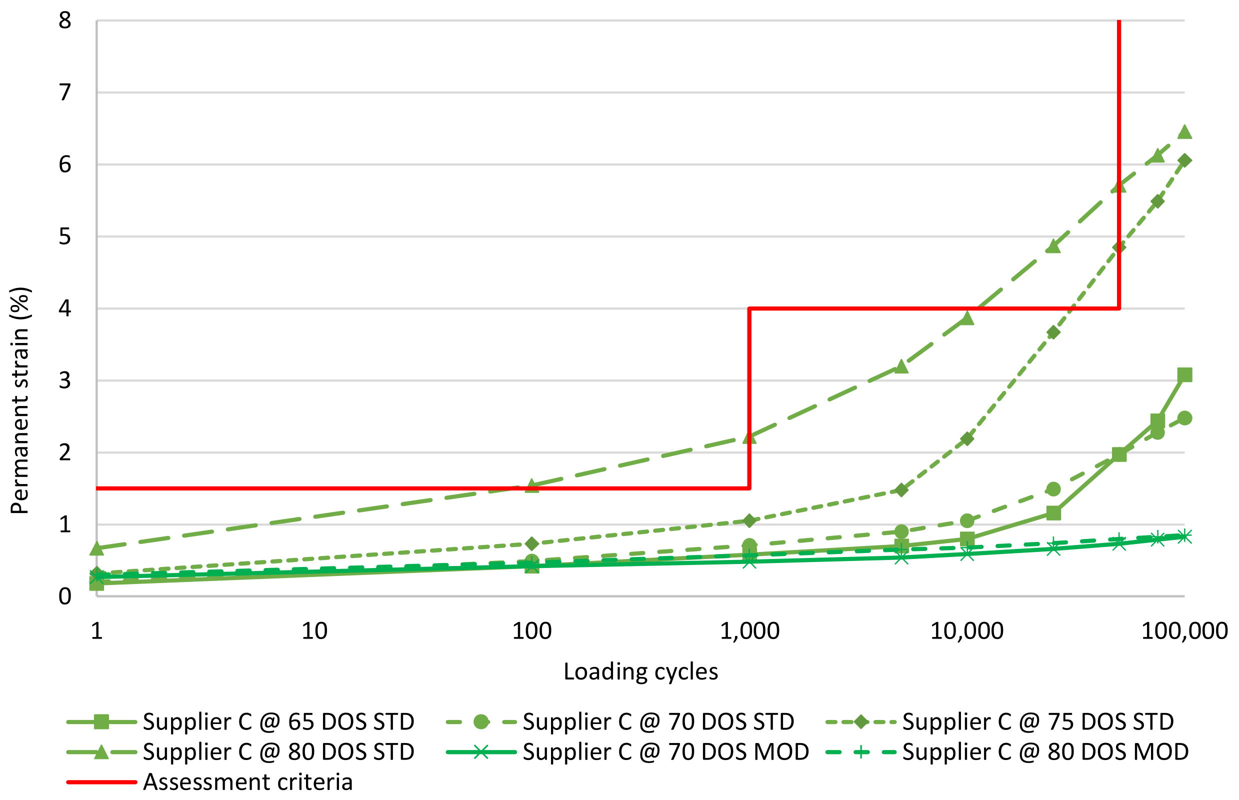
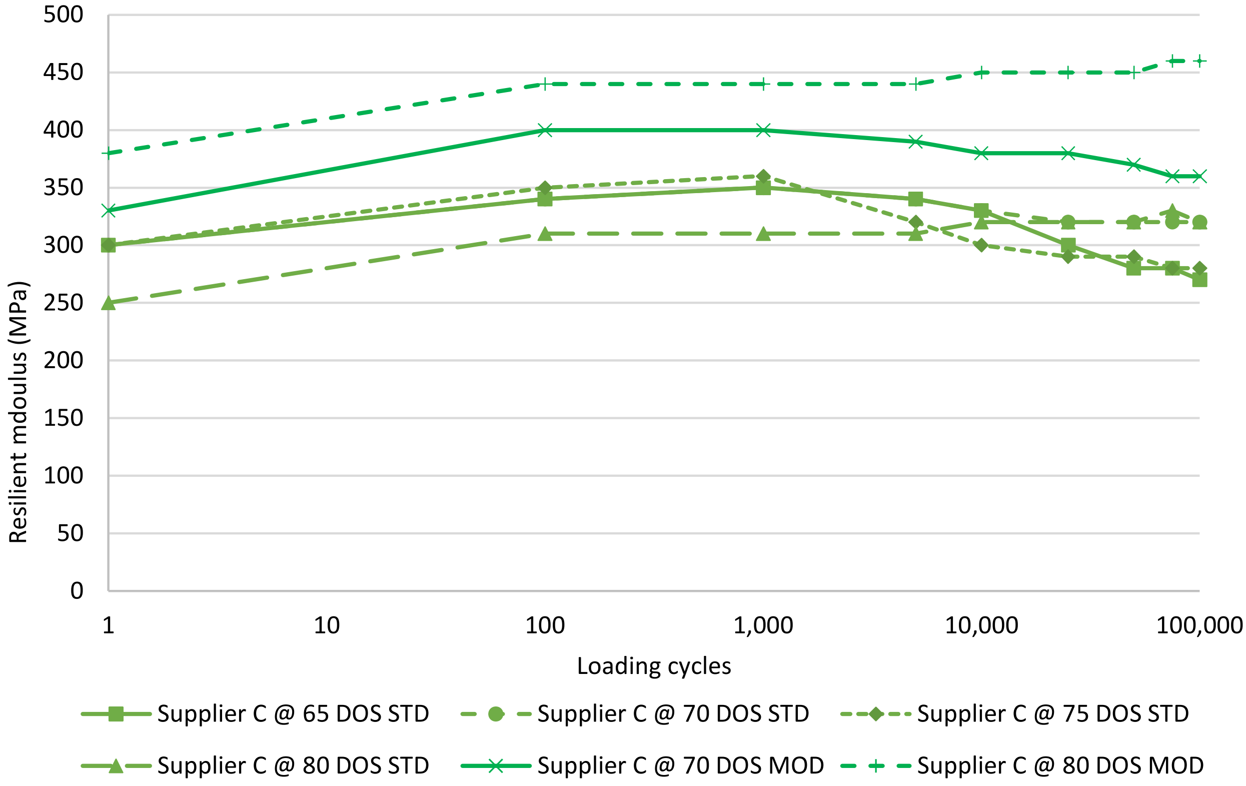


Figure 3.6: Supplier C resilient modulus RLT results



Supplier D

The materials from Supplier D were compacted at standard MDD was subject to RLT testing at 65%, 70%, 75% and 85% DOS while samples prepared at modified MDD were tested at 70% and 80% DOS, summarised in Table 3.4 and depicted in Figure 3.7 for permanent strain against loading cycles. This shows that for the materials prepared using standard compaction at 65%, 70% and 75% DOS, the material conforms to the TMR assessment criteria up to 100 000 cycles whereas the 80% DOS sample was compliant at 50 000 cycles but exceeded 5.0% permanent strain at 100 000 cycles. Notably, both samples tested using modified compaction did not exceed 1.0% permanent strain up to 100 000 cycles.

Supplier D resilient modulus results for samples prepared at standard and modified MDD are depicted in Figure 3.8. The samples prepared at standard MDD for all DOS levels show relatively consistent resilient modulus values for all load cycles, ranging from 330-590 MPa. In contrast, the samples prepared at modified MDD show significantly higher resilient modulus values, ranging from 480-1440 MPa at 70% DOS and 630-1360 MPa at 80% DOS. Notably, for the modified MDD samples there is a significant reduction in modulus after 10 000 cycles from 1360-1440 MPa to 980-1090 MPa at 100 000 cycles.

Table 3.4: Supplier D RLT testing conditions

Compaction effort	Target dry density (t/m^3)	Target moisture content (%)	Target DOS (%)	Target percentage of OMC (%)
Standard	1.88	9.7	65	69
	1.88	10.4	70	74
	1.88	11.2	75	80
	1.88	11.9	80	85
Modified	1.95	9.1	70	76
	1.95	10.4	80	87

Figure 3.7: Supplier D permanent strain RLT results

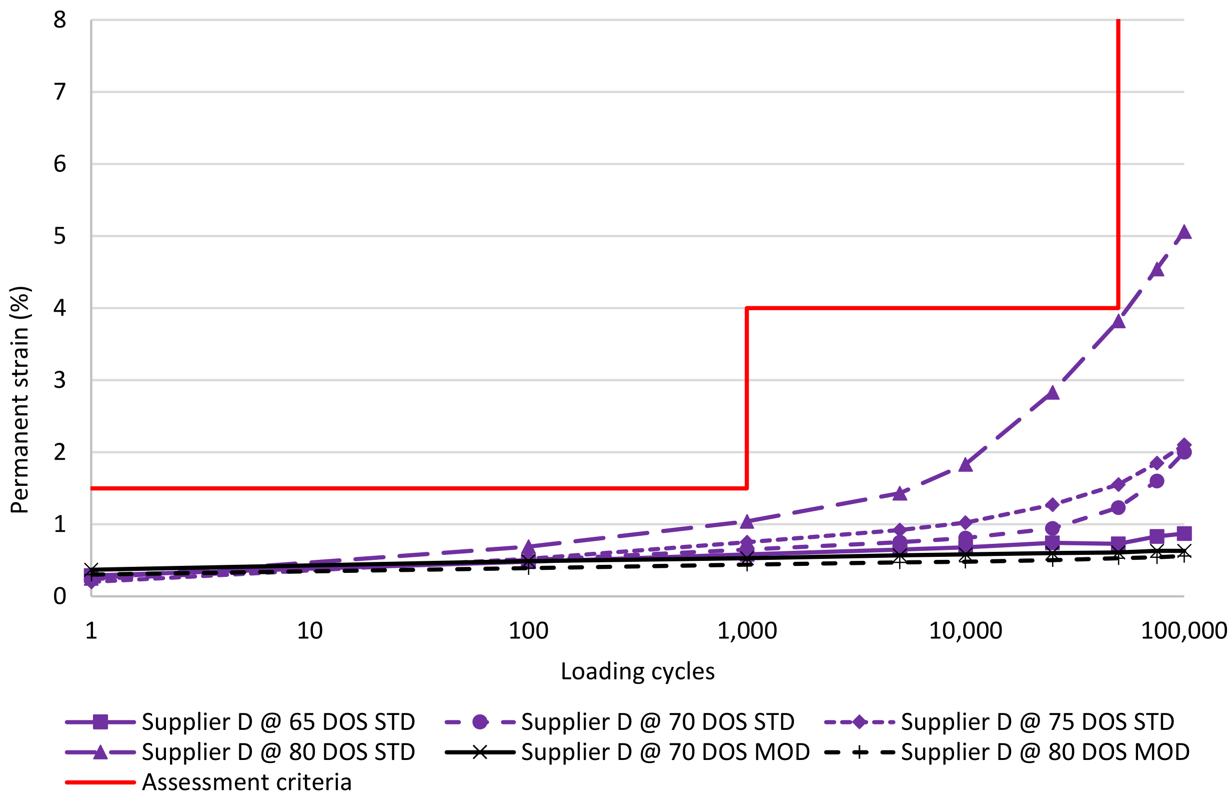
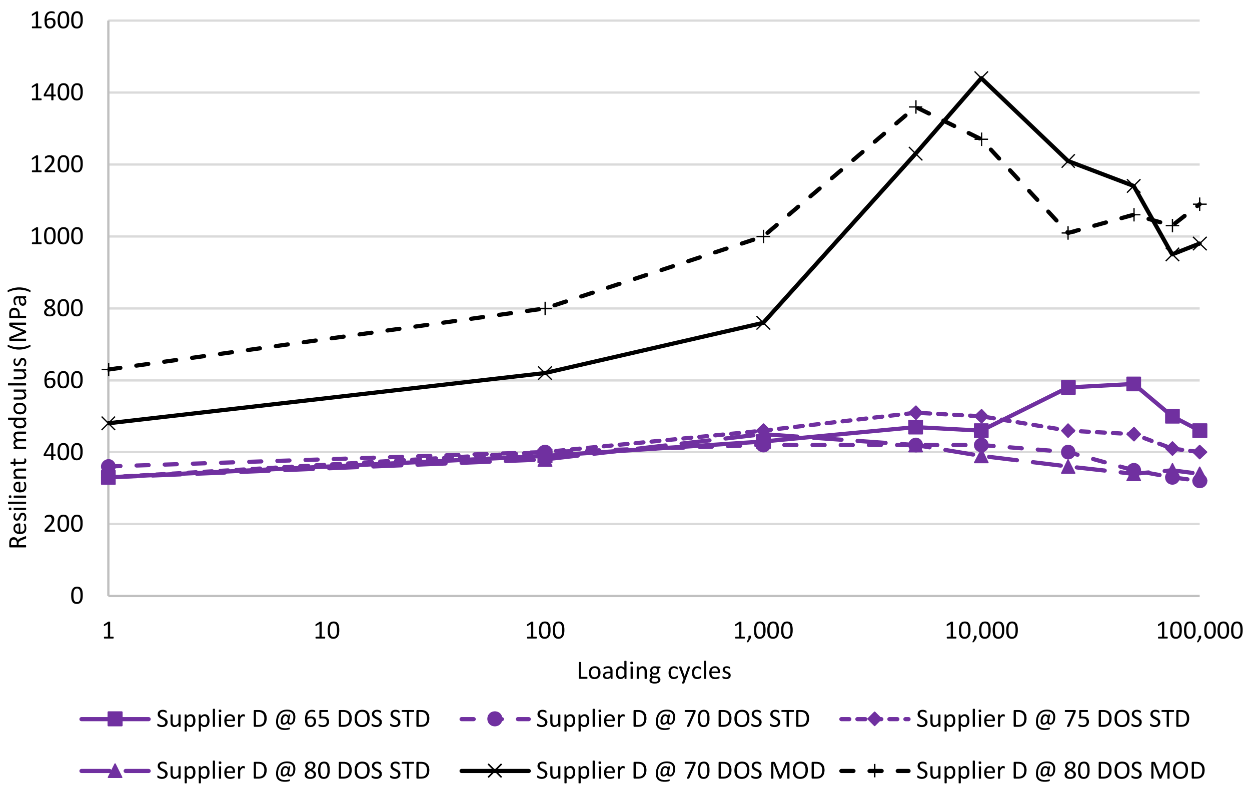


Figure 3.8: Supplier D resilient modulus RLT results



3.1.2 RM003 RLT RESULTS

Supplier F

The Supplier F RLT testing conditions at both standard and modified MDD are summarised in Table 3.5 with the permanent strain results depicted in Figure 3.9. The results show that for standard MDD, at 65% DOS and 70% DOS the material conforms to the TMR assessment criteria up to 100 000 cycles but notably, the 65% DOS sample exceeds the 1.5% strain limit at 1000 cycles whereas the 70% DOS sample narrowly complies (1.47 mm). Additionally, at 75% DOS using standard compaction the permanent strain limit is exceed at both 1000 cycles and 50 000 cycles. The material testing at modified MDD and 70% DOS or 80% DOS show approximately equal performance, not exceeding 1.0% permanent strain up to 100 000 cycles.

The resilient modulus results obtained from RLT testing for the Supplier F materials prepared at standard and modified MDD are presented in Figure 3.10. This material exhibited a relatively high range of initial resilient modulus values for the samples prepared at standard MDD (250-420 MPa). Interestingly, the highest initial resilient modulus for the standard MDD samples was observed at 70% DOS (420 MPa) while the lowest value was obtained at 75% DOS (250 MPa). However, after 1000 cycles the resilient modulus of the 70% DOS sample dropped to 320 MPa at 100 000 cycles whereas the 65% DOS sample showed little change between 1000 and 100 000 cycles, finishing with a value of 380 MPa. Similar to observed for the RM001 materials, the samples prepared at modified MDD show higher resilient modulus values, ranging from 400-480 MPa at 70% DOS and 410-680 MPa at 80% DOS, which increased with loading cycles.

Table 3.5: Supplier F RLT testing conditions

Compaction effort	Target dry density (t/m^3)	Target moisture content (%)	Target DOS (%)	Target percentage of OMC (%)
Standard	1.78	11.8	65	79
	1.78	12.7	70	85
	1.78	13.6	75	91
Modified	1.91	10.0	70	77
	1.91	11.5	80	88

Figure 3.9: Supplier F permanent strain RLT results

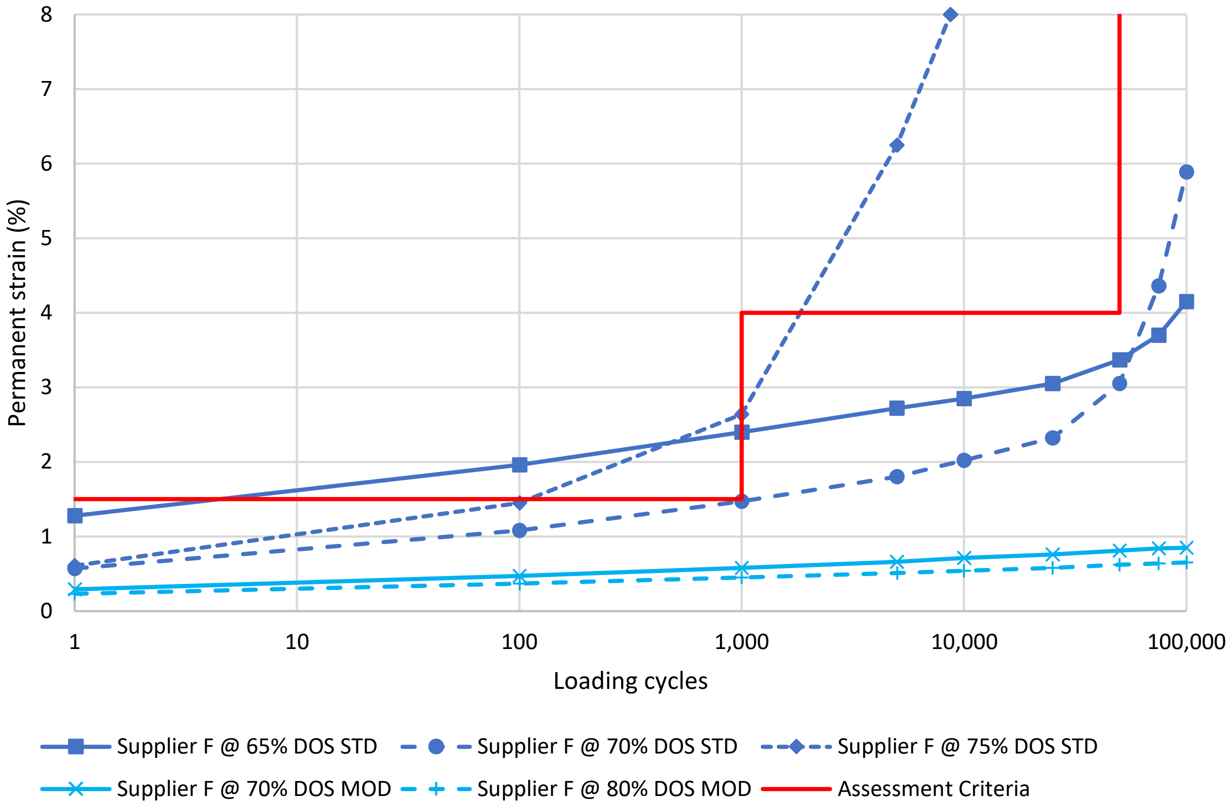
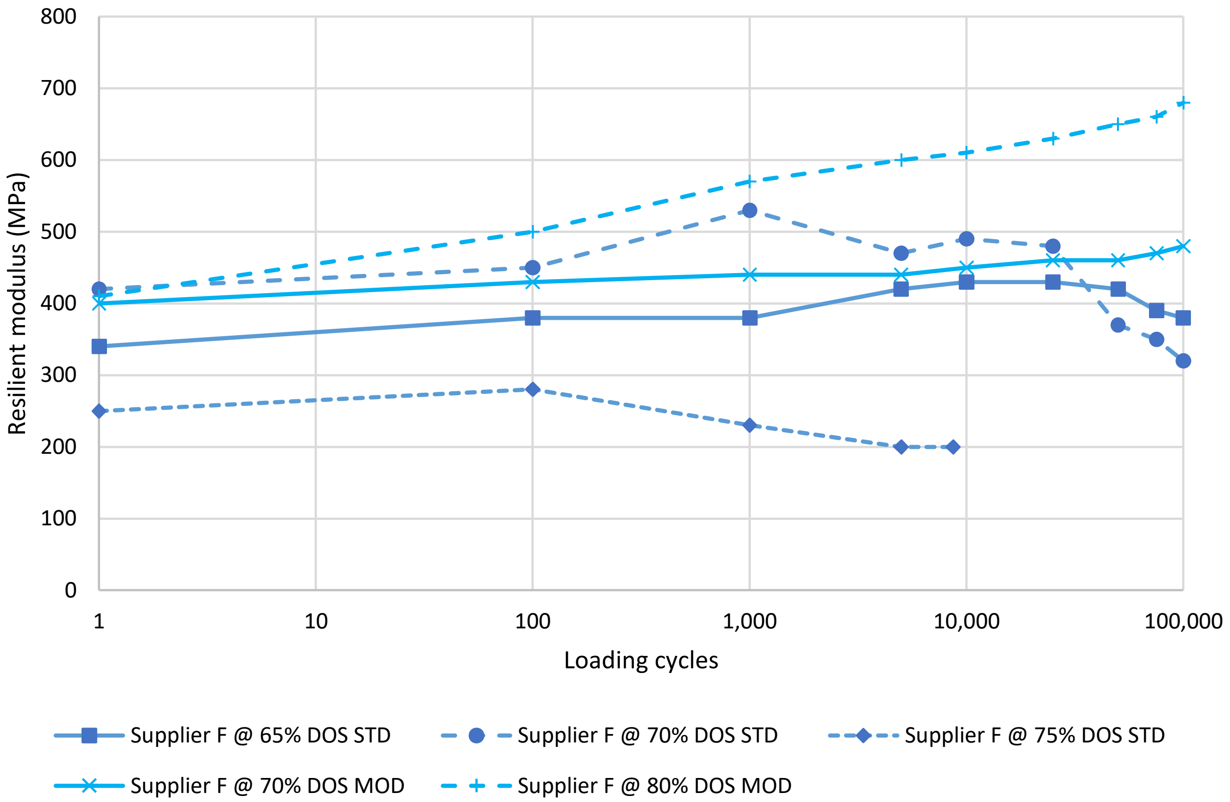


Figure 3.10: Supplier F resilient modulus RLT results



Supplier G

Supplier G provided two material blends that were subject to RLT testing, one containing 0% glass and the other containing 20% glass. The testing conditions are summarised in Table 3.6 and the permanent strain results are depicted in Figure 3.11 and Figure 3.12 for the 0% glass and 20% glass mix, respectively. The 0% mix shows that at 65% DOS and 70% DOS the material comfortably conforms to the 4.0% permanent strain limit up to 50 000 cycles, although the material tested at 75% DOS exceeds the 8.0% permanent strain testing limit at approximately 25 000 cycles. Similar to the previous RLT tests for RM001 and RM003 materials conducted at modified MDD and 70% DOS or 80% DOS, the permanent strain did not exceed 1.0% at 100 000 cycles. Notably, the mix containing 20% glass only exceed 1.0% permanent strain at 100 000 cycles at standard MDD with 75% DOS and 80% DOS, thus indicating that the performance of the material from Supplier G is improved with 20% glass contents.

The resilient modulus RLT results for the 0% glass mix and the 20% glass mix are presented in Figure 3.13 and Figure 3.14, respectively. It can be observed that for the 0% glass mix the resilient modulus values for the 65% DOS sample prepared at standard MDD showed the highest resilient modulus of all samples tested with a range of values from 580-910 MPa, significantly higher than the samples at 70% DOS (220-400 MPa) and 75% DOS (290-420 MPa). The 0% glass mix samples prepared at modified MDD showed more consistent results with a range of 450-590 MPa at 70% DOS and 380-480 MPa at 80% DOS.

The results for the 20% glass mix (Figure 3.14) show relatively consistent results for the samples prepared at standard MDD at 65%, 70% and 75% DOS ranging from 350-570 MPa, whereas the 80% DOS sample showed more variation, with a range of 440-820 MPa. Additionally, the modified MDD samples started out with higher initial moduli than the standard MDD samples with 460 MPa at 70% DOS and 690 MPa at 80% DOS but after 100 000 cycles finished with approximately the same modulus (520-570 MPa) as the 65%, 70% and 75% DOS samples prepared at standard MDD. These resilient modulus values for Supplier G indicate these materials are suited for subbase applications in accordance with typical usages of natural Type 2.3 materials.

Table 3.6: Supplier G RLT testing conditions

Compaction effort	Glass content (%)	Target dry density (t/m^3)	Target moisture content (%)	Target DOS (%)	Target percentage of OMC (%)
Standard	0	1.92	9.1	65	67
		1.92	9.8	70	73
		1.92	10.6	75	79
	20	1.92	8.8	65	68
		1.92	9.4	70	72
		1.92	10.1	75	78
		1.92	10.8	80	83
Modified	0	2.01	8.2	70	75
		2.01	9.4	80	85
	20	2.01	7.8	70	74
		2.01	8.9	80	85

Figure 3.11: Supplier G (0% glass) permanent strain RLT results

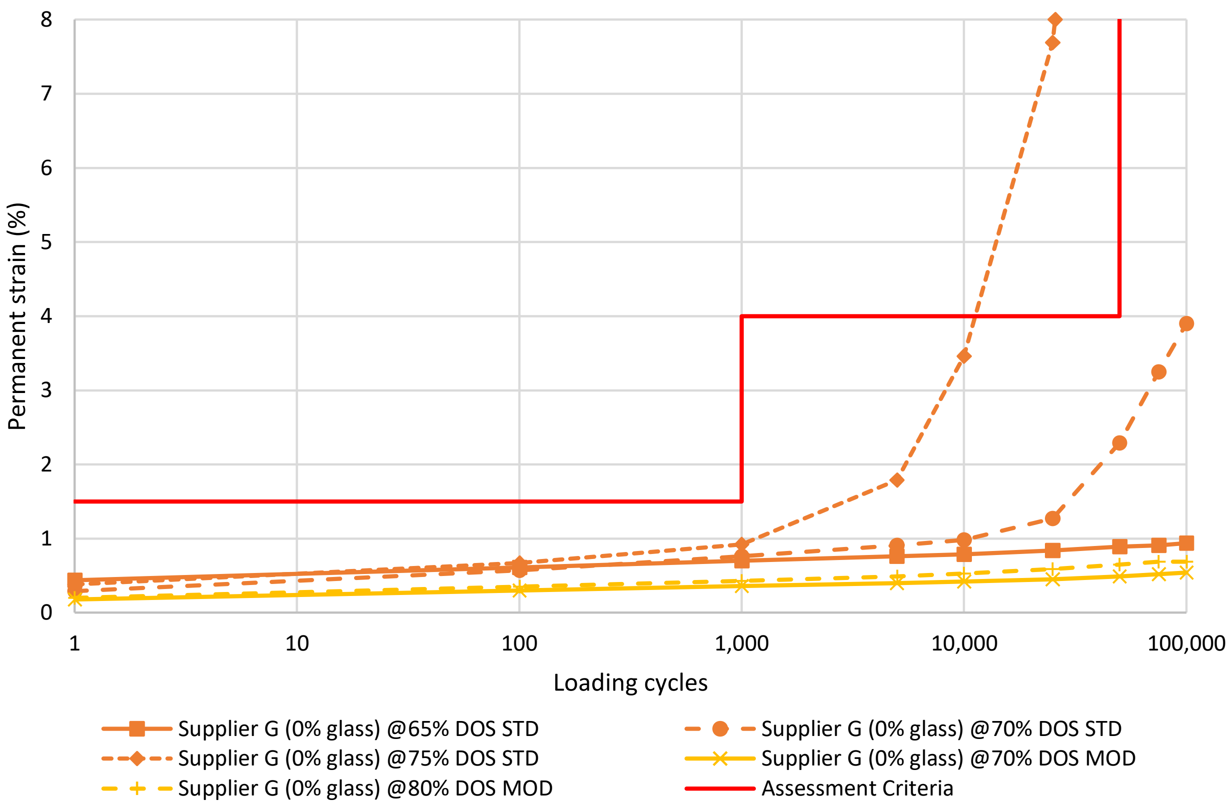


Figure 3.12: Supplier G (20% glass) permanent strain RLT results

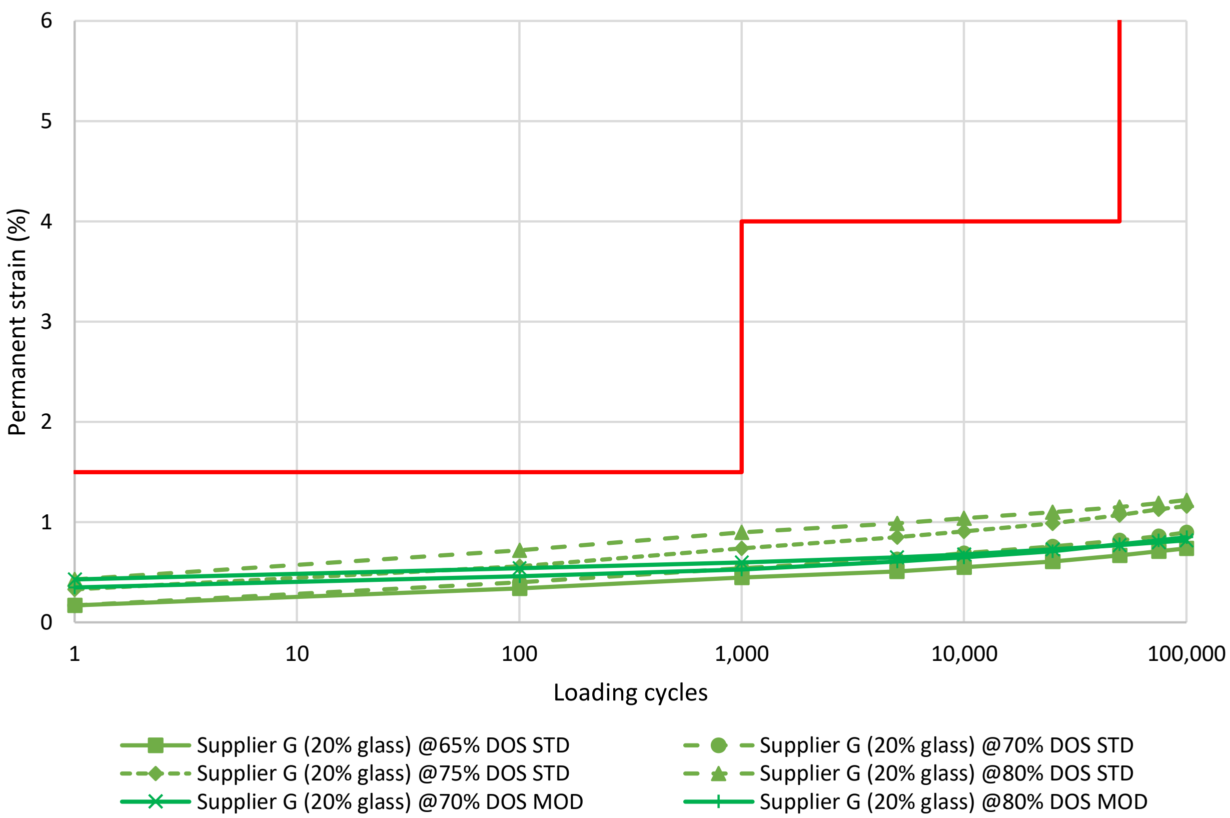


Figure 3.13: Supplier G (0% glass) resilient modulus RLT results

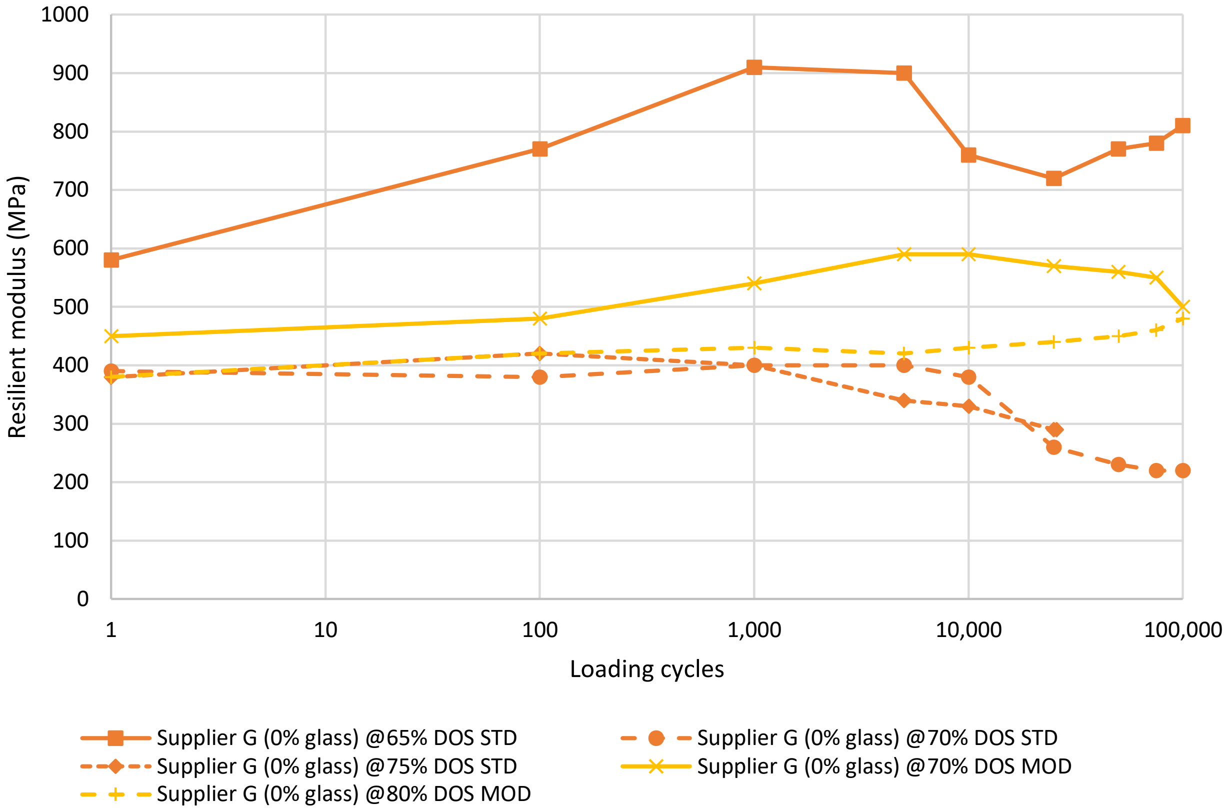
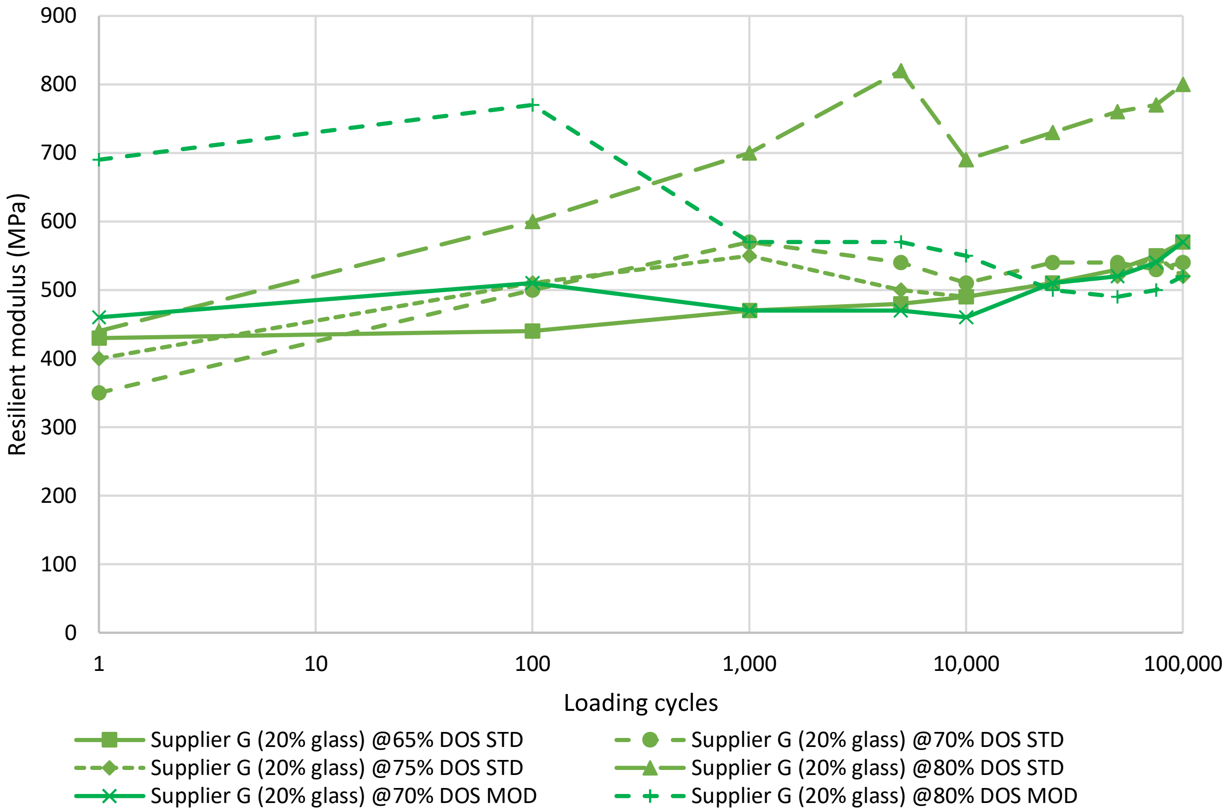


Figure 3.14: Supplier G (20% glass) resilient modulus RLT results



3.1.3 ANALYSIS

RM001 materials

Resilient modulus

The RLT resilient modulus results are presented in Figure 3.15 and Figure 3.16 for the samples prepared at standard MDD and modified MDD, respectively. Additionally, to supplement the laboratory testing of the recycled materials, TMR supplied a complete set of data from a TMR project for six commonly used Type 2.1 natural quarried material suppliers (identified as Supplier 1 to Supplier 6) which is also shown in Figure 3.15 and Figure 3.16. Although there are no TMR requirements for resilient modulus determined using the RLT test, the presumptive modulus value of 350 MPa for RM001 materials in accordance with the TMR pavement design supplement (TMR 2018c), was included for discussion.

Figure 3.15 shows Supplier A only achieves the 350 MPa benchmark at 70% DOS while Supplier B and Supplier C achieve 350 MPa at 65% DOS. All samples from Supplier D exceeded 350 MPa. Comparatively, the natural quarried material dataset includes few values above 60% DOS making comparisons difficult. It is noted that the natural quarried material show values below 350 MPa at 50% DOS.

The resilient modulus of the samples prepared at modified MDD depicted in Figure 3.16 shows that most samples exceed the 350 MPa benchmark. Notably, the RM001 materials all show compliance with performance similar to, if not better than the natural quarried materials. Comparison of the samples prepared at standard MDD (Figure 3.15) and modified MDD show that when the RM001 materials are compacted at modified MDD the materials have higher resilient modulus values.

Figure 3.15: RM001 vs. Type 2.1 natural quarried material prepared at standard MDD, RLT resilient modulus testing results at 1000 cycles

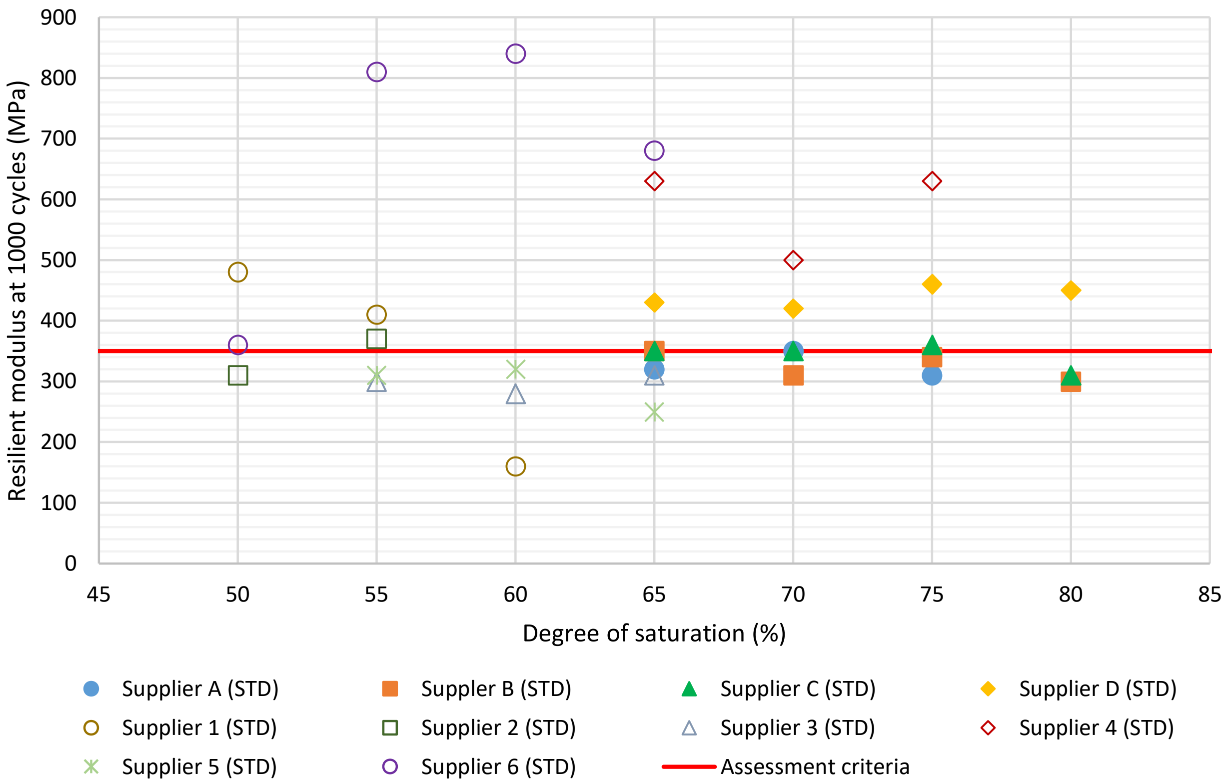
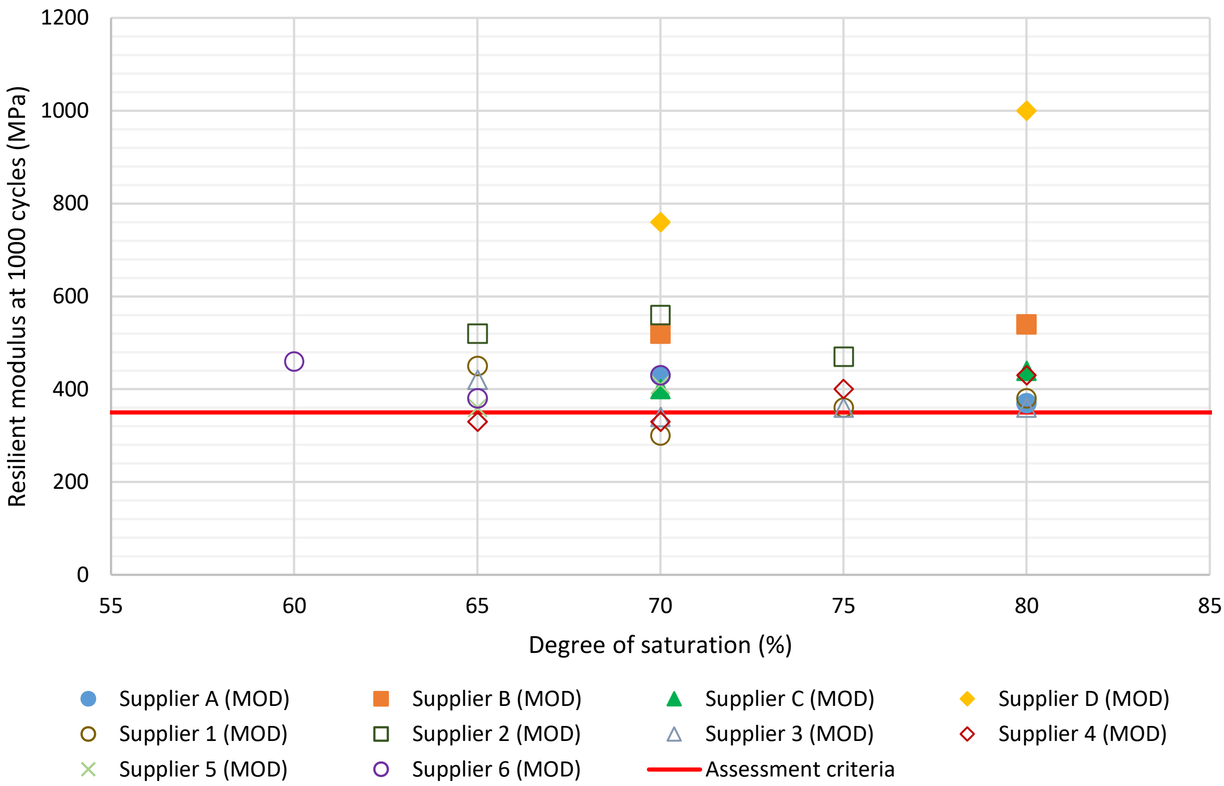


Figure 3.16: RM001 vs. Type 2.1 natural quarried material prepared at modified MDD, RLT resilient modulus testing results at 1000 cycles



Permanent strain

The permanent strain from each of the RM001 materials tested at standard MDD at 50 000 cycles is presented in Figure 3.17. The results show the majority of the samples tested were compliant to the 4.0% permanent strain limit, as stated in MRTS05, with the exception of two samples at 75% DOS, one from Supplier A and one from Supplier C and one sample at 80% DOS from Supplier C compacted at standard MDD. Notably, in comparison to the RM001 materials, the quarried material RLT results show more NCs to the 4.0% strain limit at less than 70% DOS, indicating that recycled material mixes may perform better in service than some quarried materials.

The RLT permanent strain for the RM001 materials and Type 2.1 natural quarried materials prepared at modified MDD are presented in Figure 3.18. This shows the RM001 samples compacted at modified MDD at both 70% DOS and 80% DOS, did not exceed 1.0% permanent strain. Comparison of the samples prepared at standard MDD (Figure 3.17) and modified MDD (Figure 3.18) shows that when the RM001 materials are compacted at modified MDD the materials have significantly improved performance. Similarly, the Type 2.1 natural quarried materials prepared at modified MDD also performed better than the samples prepared at standard MDD.

Based on the data presented, it is recommended that for RM001 materials the maximum DOS is 70%. Although the data may indicate a higher value, limiting the maximum DOS to 70% will account for potential variability in material quality and testing while the increased use of recycled materials in implemented in Queensland. A comparison of the RM001 materials at 70% DOS is shown in Figure 3.19.

Figure 3.17: RM001 vs. Type 2.1 natural quarried material prepared at standard MDD, RLT permanent strain testing results at 50 000 cycles

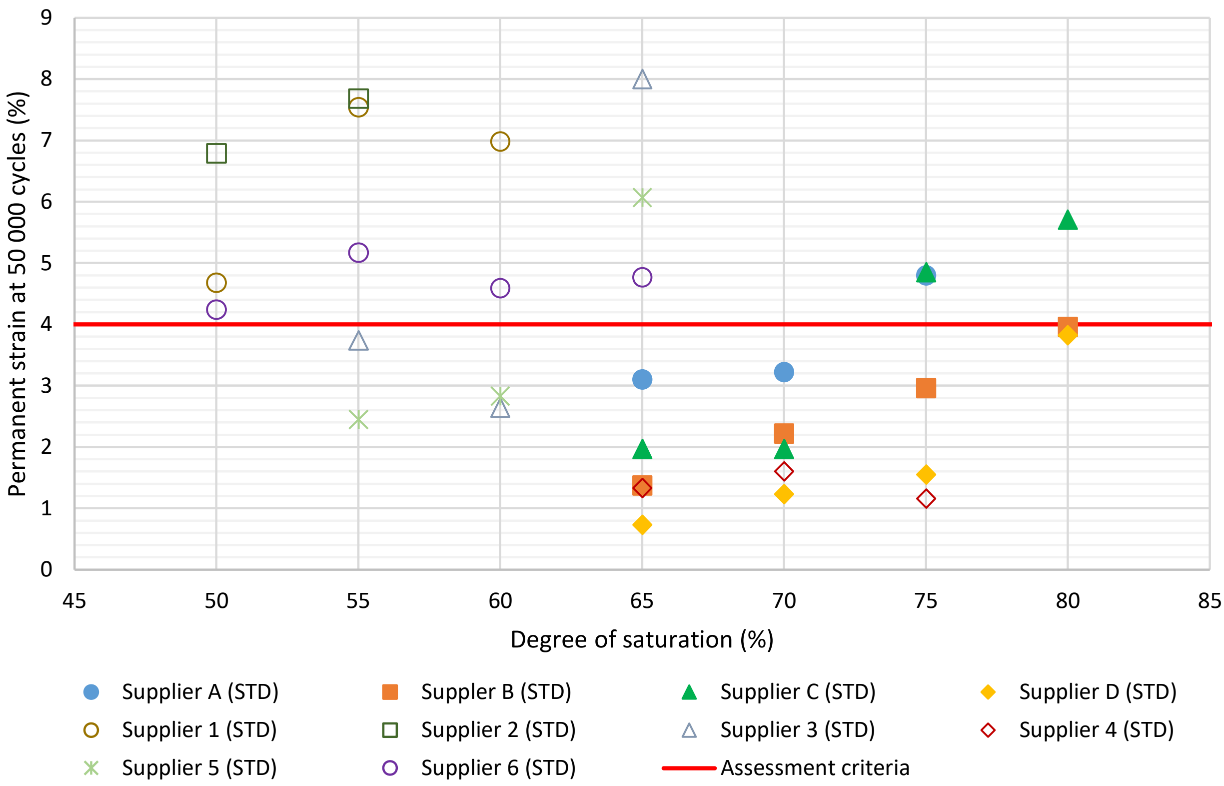


Figure 3.18: RM001 vs. Type 2.1 natural quarried material prepared at modified MDD, RLT permanent strain testing results at 50 000 cycles

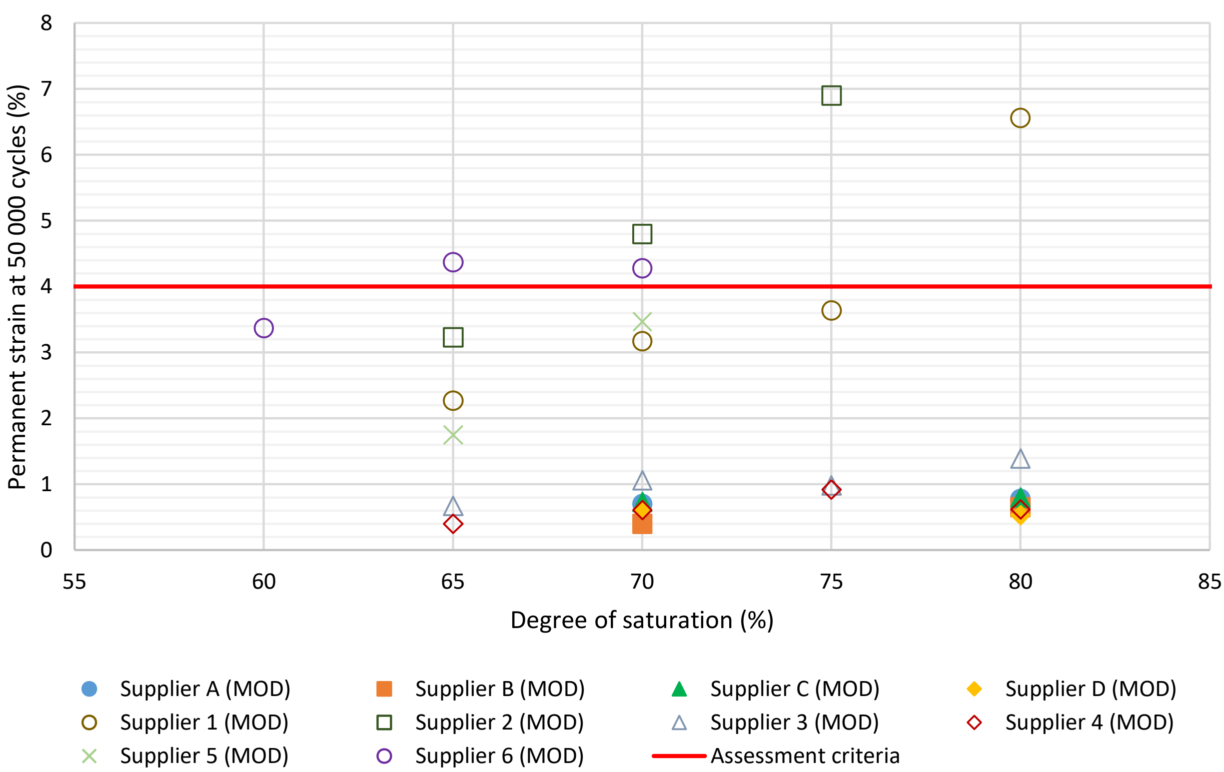
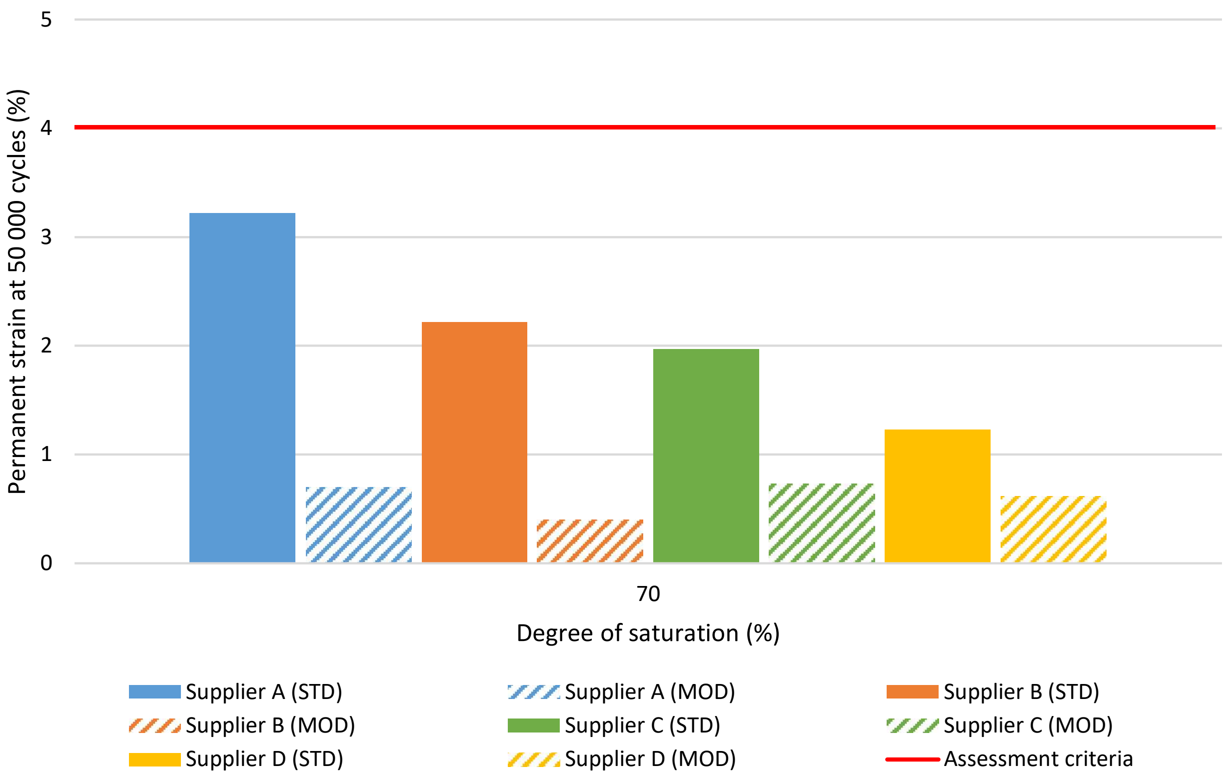


Figure 3.19: RM001 RLT permanent strain testing results at 50 000 cycles and 70% DOS

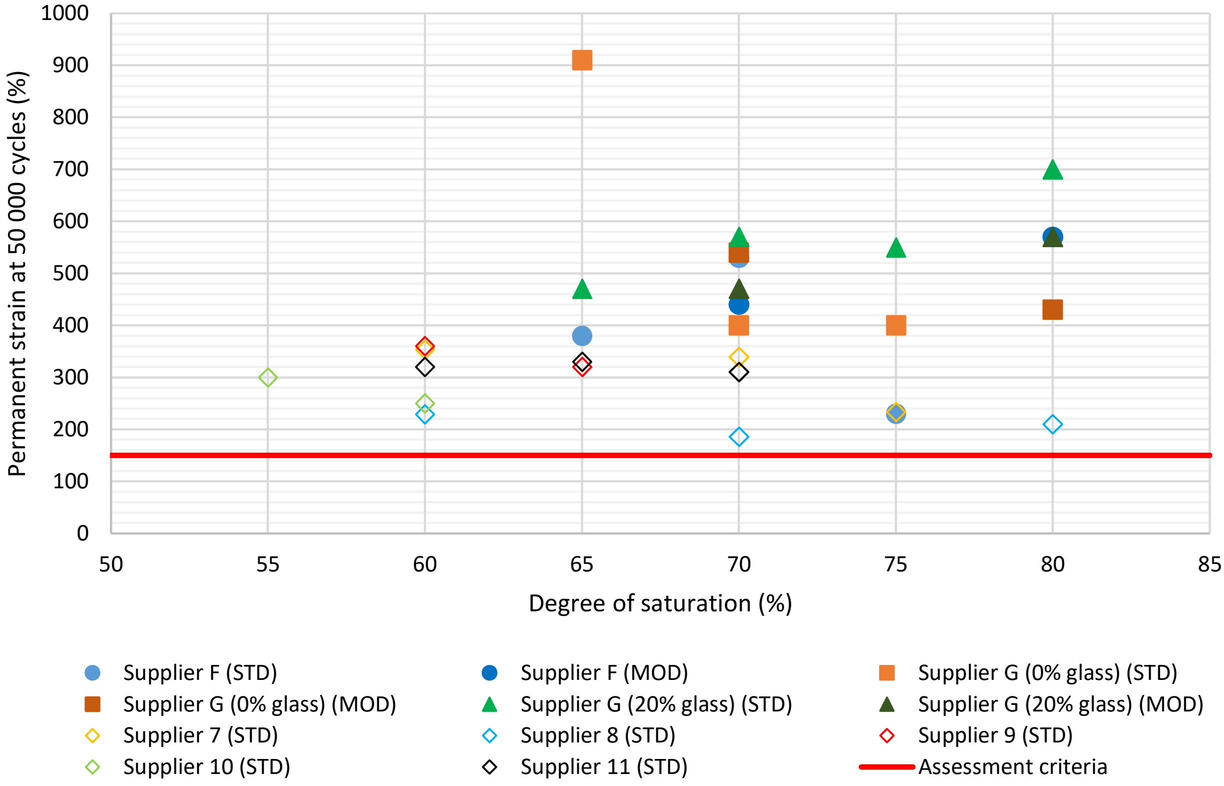


RM003 materials

Resilient modulus

The RM003 resilient modulus RLT results prepared using standard and modified MDD is depicted in Figure 3.20. This also shows RLT data from five Type 2.3 natural quarried material suppliers provided by TMR (identified as Supplier 7 to Supplier 11). The presumptive modulus value of 150 MPa for RM003 materials in accordance with the TMR pavement design supplement (TMR 2018c) was included for discussion. This shows that all the data exceeds the 150 MPa benchmark and the RM003 materials generally show higher values than the natural quarried materials. Interestingly, the resilient modulus of the Supplier F and Supplier G with 20% glass prepared at modified MDD show lower values than the samples prepared at standard MDD. These results indicate RM003 are suitable for substitution with natural quarried Type 2.3 materials.

Figure 3.20: RM003 prepared at standard MDD and modified MDD vs. Type 2.3 natural quarried material prepared at standard MDD, RLT resilient modulus testing results at 1000 cycles

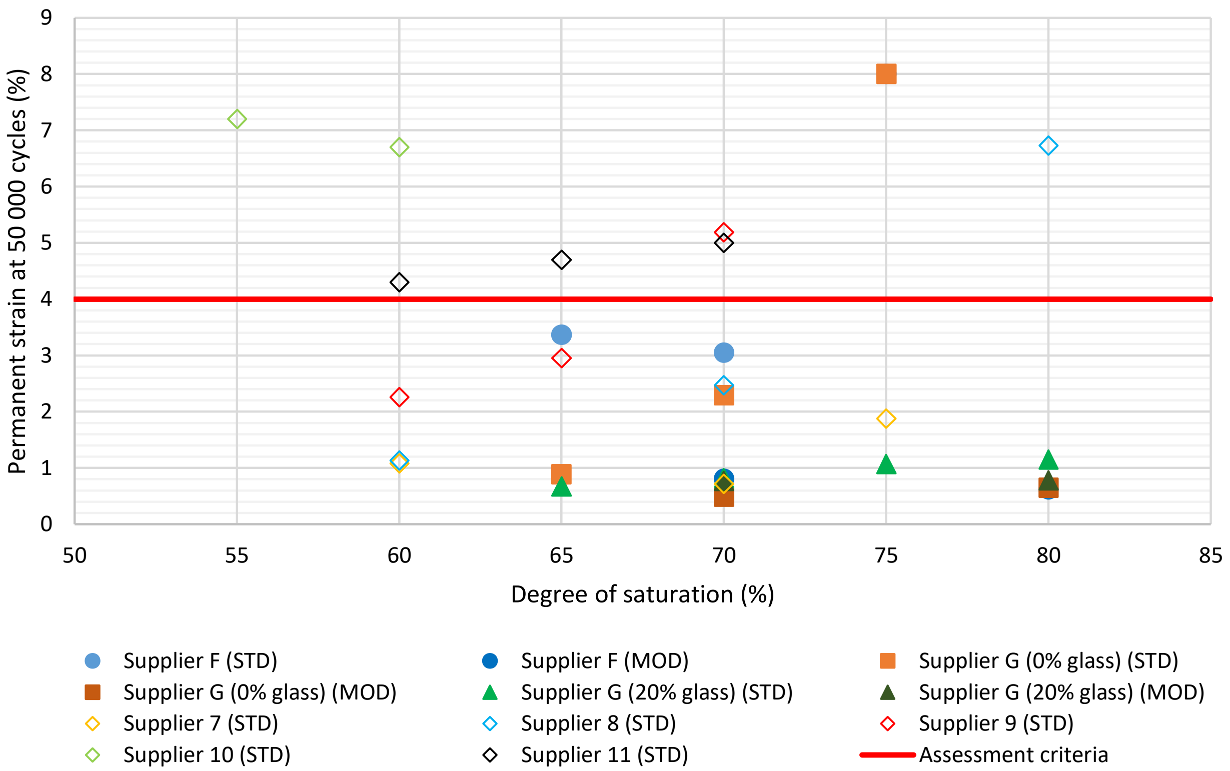


Permanent strain

The permanent strain results from each of the RM003 suppliers tested using samples prepared using standard and modified MDD at 50 000 cycles is presented in Figure 3.21. The results show that the only RM003 material that exceeded the 4.0% limit with the standard MDD was the material from Supplier G with 0% glass at 75% DOS, where the test was stopped after approximately 25 000 cycles due to reaching the maximum permanent strain (8.0%). Supplier G with 20% glass performed well at all the DOS levels. In comparison to the natural quarried materials, the RM003 showed less non-conformance, similar to the RM001 materials (Figure 3.17). Furthermore, the results show that for the samples prepared at modified MDD at both 70% DOS and 80% DOS, the permanent strain did not exceed 1.0%. This shows significantly improved performance compared to the samples prepared at standard MDD, similar to the RM001 materials.

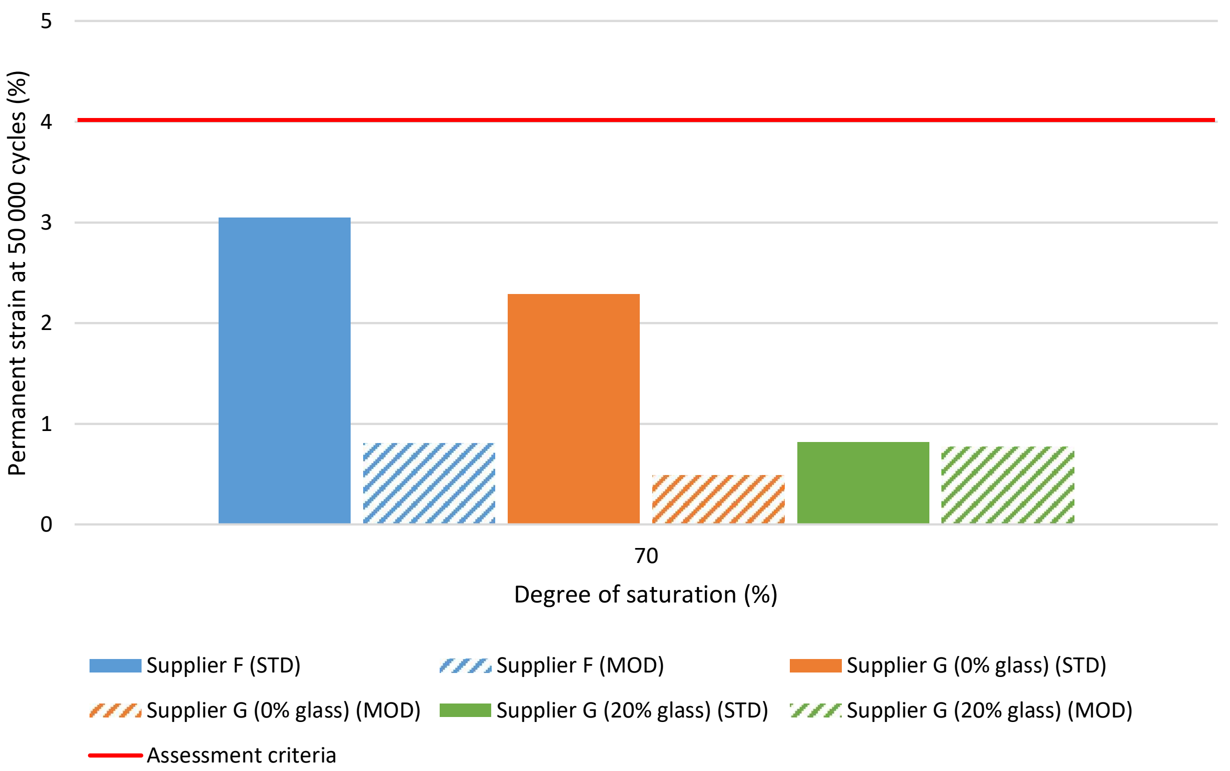
It is recommended that as per the RM001 material DOS limit, RM003 materials are limited to a maximum DOS to 70%. A comparison of the RM003 materials at 70% DOS is shown in Figure 3.22

Figure 3.21: RM003 prepared at standard MDD and modified MDD vs. Type 2.3 natural quarried material prepared at standard MDD, RLT permanent strain testing results at 50 000 cycles



Note: Supplier 10 sample tested at 55% DOS was terminated at 36 287 cycles.

Figure 3.22: RM003 RLT permanent strain testing results at 50 000 cycles and 70% DOS



3.2 WHEEL TRACKING

The wheel tracker test provides an indication of the deformation potential of the material. Testing was conducted in accordance with TMR test method Q149 *Deformation of Granular Material* – *Wheel Tracker* (TMR 2020a) at the TMR Bulwer Island Laboratory. Additionally, although not currently specified by TMR, a report on *Unbound Granular Characterisation* (Department of Main Roads 2002) noted that a maximum final rut depth of 2.5 mm at 10 000 passes is acceptable.

3.2.1 RM001 WHEEL TRACKER RESULTS

The wheel tracker test results for each of the suppliers at 70% DOS and 80% DOS prepared at standard MDD are summarised in Table 3.7. 70% and 80% DOS were chosen for testing based on the outcomes of the RLT, with these limits being considered to cover the point at which material may perform satisfactorily (70%) and begin to show signs of moisture sensitivity (80%). It is worth noting that 80% DOS equates to approximately 88% of OMC, which is typically close to the placement moisture content of lightly bound materials

The results show that at 70% DOS permanent deformation of the tested materials does not show significant variation between materials with a measured permanent deformation below around 1.0 mm after 10 000 passes. At 80% DOS the materials from Supplier A and Supplier B show approximately 2.0 mm deformation whereas the Supplier C and Supplier D material both showed a deformation exceeding 4.00 mm. This shows only the material from Supplier C and Supplier D at 80% DOS would exceed the acceptance criteria.

Table 3.7: Summary of RM001 wheel tracker test results

Supplier	Standard dry density (t/m^3)	DOS (%)	Deformation at 5 000 cycles (10 000 passes) (mm)	Acceptance criteria (mm)*
A	1.80	70	0.72	≤ 2.5
	1.80	80	2.18	≤ 2.5
B	1.81	70	1.15	≤ 2.5
	1.81	80	2.49	≤ 2.5
C	1.91	70	0.90	≤ 2.5
	1.91	80	4.21	≤ 2.5
D	1.88	70	0.95	≤ 2.5
	1.88	80	4.46	≤ 2.5

**Note: Indicative acceptance criteria only.*

3.2.2 RM003 WHEEL TRACKER RESULTS

Similar to the RM001 materials, wheel tracker testing was undertaken on three RM003 materials prepared at 70% DOS and 80% DOS using standard MDD, as summarised in Table 3.8. Results from Supplier G showed that at 70% DOS the material containing 0% glass showed less deformation (0.24 mm) than the sample with 20% glass (0.90 mm), however, at 80% DOS the 0% glass sample had a greater deformation (1.40 mm) than the 20% glass sample (1.25 mm). This indicates that the material from Supplier G performs well regardless of glass content. Notably, the sample from Supplier F showed a deformation of 4.71 mm at 70% DOS and a deformation of 14.98 mm at 80% DOS after only 650 cycles, postulated to have been caused by moisture sensitive particles although this material showed adequate RLT performance. The material from Supplier F at 70% DOS and 80% DOS exceeded the 2.5 mm acceptance criteria.

Table 3.8: Summary of RM003 wheel tracker test results

Supplier	Standard dry density (t/m^3)	DOS (%)	Deformation at 5 000 cycles (10 000 passes) (mm)	Acceptance criteria (mm) (1)
F	1.78	70	4.71	≤ 2.5
	1.78	80	14.98 (2)	≤ 2.5

Supplier	Standard dry density (t/m³)	DOS (%)	Deformation at 5 000 cycles (10 000 passes) (mm)	Acceptance criteria (mm) (1)
G (0% glass)	1.92	70	0.24	≤ 2.5
	1.92	80	1.40	≤ 2.5
G (20% glass)	1.92	70	0.90	≤ 2.5
	1.92	80	1.25	≤ 2.5

1. *Indicative acceptance criteria only.*
2. *Test was terminated at 650 cycles.*

3.3 EXTRA LARGE WHEEL TRACKER

The XL-WT test, utilising the Austrack wheel tracker and slab compactor is used to assess the permanent deformation performance of granular material and is intended to be used as a complementary or alternative test to the RLT test. The XL-WT test better represents in-service loading conditions by modelling the effect of a rolling wheel on a specimen of material in laboratory (Austroads 2017).

This test was performed by preparing a specimen (length = 700 mm, width = 500 mm, and height = 300 mm) using approximately 350 kg of raw material and compacting in six 50 mm thick layers using a segmental steel compaction foot. The XL-WT test was performed under an 8 kN load, applied by a smooth tyre inflated to 600 kPa for 40 000 cycles (80 000 passes) or until the specimen shows signs of significant deformation (> 18 mm) in accordance with Austroads Test Method AGPT/T054 *Determinate of Permanent Deformation Characteristics of Unbound Granular Materials by the Wheel-tracking Test* (Austroads 2015). Testing was undertaken on RM001 samples from Supplier B, Supplier C and Supplier D in ARRB National laboratory in Melbourne using a target DOS of 75% and the detailed test report may be found in Appendix A.

The XL-WT results for each of the tested RM001 materials are summarised in Table 3.9 while the results of standard and marginal quarried material from Austroads (2017) are presented in Table 3.10. Comparisons between the RM001 results and quarried material results show that the RM001 materials exhibited much lower deformation values at similar moisture contents (where 75% DOS is approximately 80% OMC). Additionally, the RM001 material surface deformation and maximum rut depth results are depicted in Figure 3.23 and Figure 3.24. This shows that the material from Supplier D exhibited the least permanent deformation at approximately 1.2 mm whereas the Supplier B material exhibited a deformation of approximately 7.9 mm after 40 000 cycles. Similarly, Supplier D showed the lowest maximum rut depth at approximately 1.9 mm while Supplier D showed approximately 11.4 mm after 40 000 cycles. It is important to note that at the time of writing there is no robust or endorsed acceptance criteria for the XL-WT test.

Compared to the wheel tracker results at 70% DOS, the Supplier C (0.90 mm) and Supplier D (0.95 mm) results were approximately equal whereas Supplier B (1.15 mm) exhibited more deformation. At 80% DOS the wheel tracker showed inverse results with Supplier B performing the best (2.49 mm at 80% DOS), followed by Supplier C (4.21 mm at 80% DOS) and Supplier D (4.46 mm at 80% DOS). Notably, in comparison to the RLT results for samples prepared using standard MDD, the performance follows a similar trend to the XL-WT with Supplier D showing the best results, followed by Supplier C and Supplier B at 70% DOS. However, it is important to note that this is based on limited recycled material samples.

It is important to note that the XL-WT test was not performed on the RM003 materials, and as such, are not available for comparisons.

Table 3.9: Summary of RM001 XL-WT results

Supplier	DD/MDD std (%)	DOS (%)	Mean surface deformation (mm)		Maximum rut depth (mm)	
			100 cycles	40 000 cycles	100 cycles	40 000 cycles
B	99	75	2.2	7.9	3.5	11.4
C	98	75	1.2	3.6	1.6	5.3
D	100	75	0.7	1.2	1.0	1.9

Table 3.10: Summary of standard and marginal quarry material XL-WT results

Material	DD/MDD mod (%)	MC/OMC mod (%)	Mean surface deformation (mm)		Maximum rut depth (mm)	
			100 cycles	40 000 cycles	100 cycles	40 000 cycles
Granite standard plasticity	100	49	2.3	3.5(1)	3.5	5.5(1)
	100	65	2.5	4.6	3.3	6.3
	100	70	3.4	9.4	4.7	12.4
	102	54	3.9	6.2	4.8	7.8
	102	58	2.9	3.9	3.5	4.9
Hornfels standard plasticity	100	66	3.9	13.7	5.4	17.6
	100	64	4.2	10.3	4.9	13.8
	100	68	4.6	13.3	6.2	19.2
	99	80	8.8	13.1(2)	18.7	26.6(2)
Granite increased plasticity	96	62	6.1	16.3	7.3	19.9
	101	71	4.6	19.3(3)	9.2	41.4(3)
	101	83	11.4	19.5(4)	24.9	42.3(4)
	101	88	13.9	22.5(4)	24.1	39.9(4)
Hornfels increased plasticity	98	58	2.3	5.1	4.2	8.1
	98	75	7.1(5)	17.8(6)	7.5(4)	36.7(6)
	98	84	9.1(5)	24.2(4)	19.1(4)	51.8(4)
Granite increased plasticity+	96	59	9.0	9.4	5.1	12.4
	96	60	7.7	16.7	11.1	22.9
	97	76	10.4	21.0(3)	14.9	31.8(3)

1. *Measurement at 60 000 cycles.*
2. *Test was terminated at 500 cycles.*
3. *Test was terminated at 3000 cycles.*
4. *Test was terminated at 200 cycles.*
5. *Measurement at 50 cycles.*
6. *Test was terminated at 8000 cycles.*

Source: Adapted from Austroads (2017).

Figure 3.23: RM001 XL-WT surface deformation test results

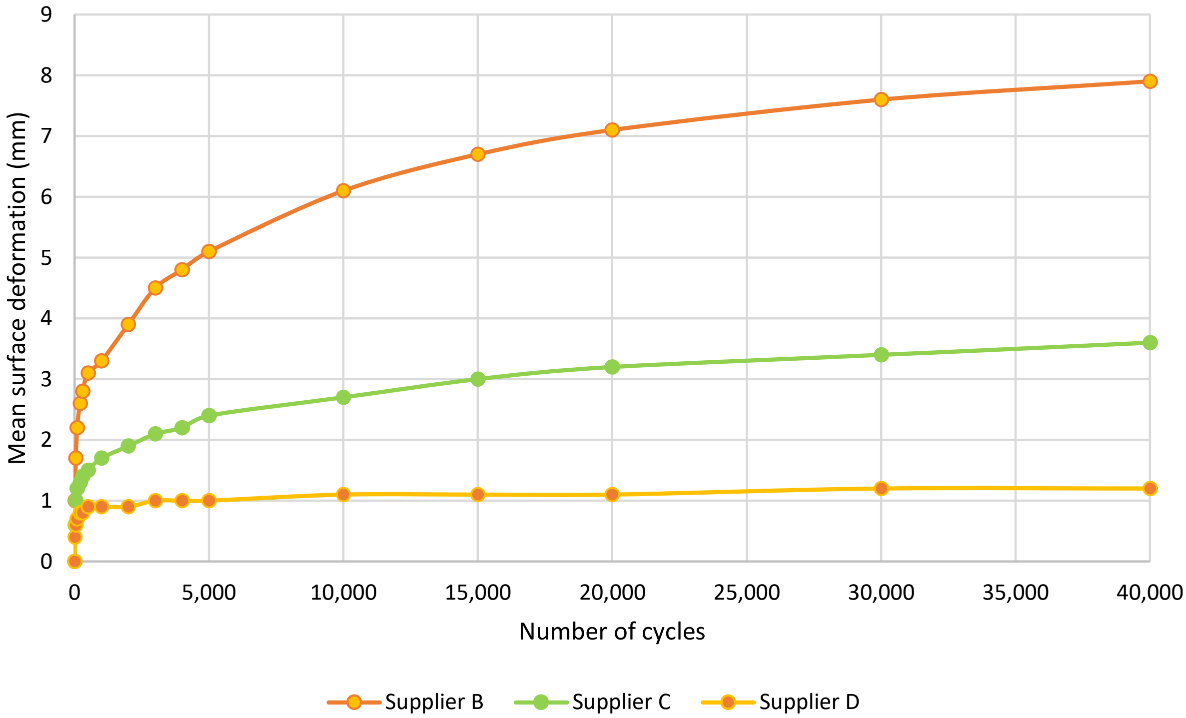
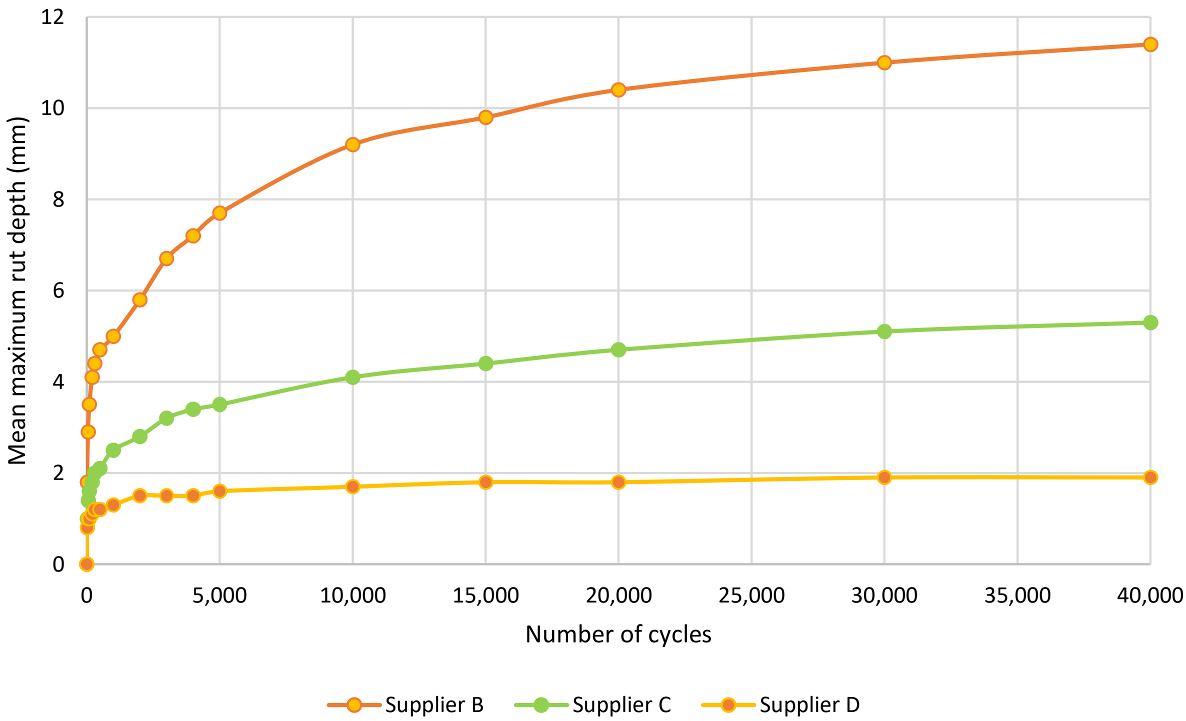


Figure 3.24: RM001 XL-WT mean maximum rut depth results



3.4 ANALYSIS OF RECYCLED MATERIAL PERFORMANCE TESTING

The recycled materials sourced throughout Queensland and selected for evaluation were subject to material characterisation testing and performance assessment using the RLT, wheel tracker and for selected mixes, the XL-WT. The test results of the material from each supplier is summarised in Table 3.11. General findings from the analysis of materials include:

- Material gradation compliance generally conformed for the RM001 materials from Supplier A, Supplier B, Supplier C and Supplier D, although all of the suppliers showed NC in the lower limit of material passing the 0.075 mm sieve. The RM003 materials all showed compliance. Notably, the RM001 materials were coarser but analysis of results indicates this did not detrimentally impact performance. In situ, increased fines would improve constructability which may not be reflected in the performance testing. In practice a finer gradation may improve workability, handling and reduce segregation, however this has not been considered in this testing.
- Atterberg limit and linear shrinkage compliance varied between suppliers for the RM001 materials, where Supplier A and Supplier B exceed the 35% LL while conforming to the other properties whereas Supplier C and Supplier D showed universal conformance.
- The suppliers generally produced material with consistent MDD and OMC, although the OMCs were high, ranging from 13.0% from Supplier G (20% glass) to 18.0% from Supplier J, both prepared using standard compaction. Modified compaction increased MDD and decreased OMC compared to the materials prepared using standard compaction, where modified MDDs were approximately 1.9-2.0 t/m^3 and the OMC had a range of 10.5% from Supplier G (20% glass) to 14.0% from Supplier A. However, high OMCs are generally related to the porous nature of the recycled aggregates, generally confirmed by the high water absorption. Notably, as the MDD of recycled materials is typically lower than observed for quarried materials, less tonnage would be required to build the same pavement, thus leading to cost savings.
- The CBR of the RM001 material from Supplier A, Supplier B, Supplier C and Supplier D is generally high and suitable for basecourse materials (≥ 80% CBR) where the CBR showed significant increases using modified compaction, improving from 130% to 280% from Supplier A. The Type 2.3 recycled materials blends showed comparatively lower CBR values at standard compaction, with only one sample from Supplier G (0% glass) showing a NC. Similar to the RM001 material, when compacted with modified compaction the CBR showed a significant increase, up from 35% to 190% using the Supplier G (0% glass) materials. This indicates recycled materials are a suitable substitute for natural quarried materials.
- Water absorption was high in both the fine and coarse particle tests, ranging from 4.6% fine from Supplier G (20% glass) to 6.7% in the coarse fraction from Supplier A. This is likely due to the porosity of the cement matrix surrounding the aggregate. Concrete is typically manufactured for very quick quality aggregates with low water absorption values.
- All materials conformed to the UCS requirements, indicating they do not act as bound materials.
- RLT permanent strain results indicate that the RM001 materials were generally compliant below 80% DOS when prepared using standard MDD whereas all the samples prepared using modified MDD at both 70% DOS and 80% DOS, the permanent strain did not exceed 1.0%. The RM003 materials performed similarly at standard MDD, where samples below 80% DOS were generally compliant, and the samples compacted using modified MDD did not exceed a permanent strain of 1.0% at 70% DOS or 80% DOS. Notably, the RM001 and RM003 materials performed better from some suppliers than the natural quarried Type 2.1 and Type 2.3 material blends, thus indicating recycled materials may perform better than natural materials in situ.
- Wheel tracker results for the RM001 samples at 70% DOS showed consistent performance between the four suppliers, ranging from 0.72 mm deformation in Supplier A materials to 1.15 mm deformation in Supplier B materials. At 80% DOS Supplier A and Supplier B show relatively similar deformation values of 2.18 mm and 2.49 mm, respectively while the deformations exhibited in Supplier C was 4.21 mm and Supplier D was 4.46 mm. The RM003 samples showed a greater variation of performance between suppliers, where Supplier F materials exhibited 4.71 mm of deformation at 70% DOS compared to the

0.24 mm and 0.90 mm measured for Supplier G 0% glass and 20% glass mixes, respectively. At 80% DOS the material from Supplier G showed 1.40 mm (0% glass) and 1.25 mm (20% glass) deformation while the Supplier F materials exhibited premature failure with 14.98 mm after only 650 cycles. RM001 and RM003 wheel tracker results generally showed conformance to the 2.5 mm indicative acceptance criteria.

- The XL-WT results shows that the material from Supplier D exhibited the least permanent deformation at approximately 1.2 mm whereas the Supplier B material exhibited a deformation of approximately 7.9 mm. It was noted that in comparison to the RLT results for samples prepared using standard MDD, the performance follows a similar trend whereas correlation to the wheel tracker results varied, especially at 80% DOS. Comparisons with natural quarried material results shows that RM001 materials exhibited much lower deformation values at similar moisture contents.
- Comparison of Supplier G (0% glass) and Supplier G (20% glass) results show that incorporating 20% glass has decreased the LL, PI and LS while maintaining the same MDD with 0.5% lower OMC for both standard and modified compaction. Additionally, the 20% glass standard CBR value (60%) was approximately double the 0% glass CBR value (35%), although the modified CBR showed a higher value for 0% glass (190%) than the 20% glass mix (160%). Notably, the RLT at standard compaction with 20% glass exhibited significantly better results than the 0% glass mix, although the modified RLT showed that the 0% glass mix performed a little better (with the standard MDD for 50 000 cycles; 20% glass mix gave low strains around 1.2% at both 75% DOS and 80% DOS, whereas 0% glass mix gave a higher strain 8% at 75% DOS). The wheel tracker results also showed marginal improvement with the 20% glass mix compared to the 0% glass mix at 80% DOS whereas the 70% DOS results were better for the 0% glass mix. This indicates that including up to 20% glass to a recycled material mix has the potential to improve mix characterisation properties and performance.

Table 3.11: Summary of recycled material testing

Supplier	Gradings	Atterberg limits and LS	Density, CBR, water absorption and UCS	RLT permanent strain at 50 000 cycles (%)	Wheel tracker surface deformation (mm)
A	• RM001 and RM002, NC in 0.075 mm sieve.	• NC in LL 37.8%. • PI of 2.0%. • LS of 1.6%.	• Std MDD 1.80 t/m³, OMC 16.5%. • Mod MDD 1.89 t/m³, OMC 14.0%. • Std CBR 130%, mod CBR 280%. • Water absorption, fine 9.7% and coarse 6.7%. • UCS 0.2 MPa.	• 65% DOS – 3.10% at 100% std MDD. • 70% DOS – 3.22% at 100% std MDD. • 75% DOS – 4.80% at 100% std MDD. • 70% DOS (mod) – 0.70% at 100% mod MDD. • 80% DOS (mod) – 0.78% at 100% mod MDD.	• 70% DOS – 0.72 mm at 100% std MDD. • 80% DOS – 2.18 mm at 100% std MDD.
B	• RM001 and RM002, NC in 2.36 mm and 0.075 mm sieve.	• NC in LL of 39.2%. • PI of 2.6%. • LS of 1.6%.	• Std MDD 1.81 t/m³, OMC 15.5%. • Mod MDD 1.90 t/m³, OMC 13.0%. • Std CBR 100%, mod CBR 220%. • Water absorption, fine 8.1% and coarse 5.0%. • UCS 0.2 MPa.	• 65% DOS – 1.37% at 100% std MDD. • 70% DOS – 2.22% at 100% std MDD. • 75% DOS – 2.96% at 100% std MDD. • 70% DOS (mod) – 0.40% at 100% mod MDD. • 80% DOS (mod) – 0.65% at 100% mod MDD.	• 70% DOS – 1.15 mm at 100% std MDD. • 80% DOS – 2.49 mm at 100% std MDD. • XL-WT – 7.9 mm at 100% std MDD.
C	• RM001 and RM002, NC in 0.075 mm sieve.	• LL of 33.2%. • PI of 2.6%. • LS of 1.4%.	• Std MDD 1.91 t/m³, OMC 14.0%. • Mod MDD 1.99 t/m³, OMC 11.5%. • Std CBR 130%, mod CBR 210%. • Water absorption, fine 6.8% and coarse 5.5%. • UCS 0.1 MPa.	• 65% DOS – 1.97% at 100% std MDD. • 70% DOS – 1.97% at 100% std MDD. • 75% DOS – 4.85% at 100% std MDD. • 80% DOS – 5.71% at 100% std MDD. • 70% DOS (mod) – 0.73% at 100% mod MDD. • 80% DOS (mod) – 0.80% at 100% mod MDD.	• 70% DOS – 0.90 mm at 100% std MDD. • 80% DOS – 4.21 mm at 100% std MDD. • XL-WT – 3.6 mm at 100% std MDD.
D	• RM001 and RM002, NC in 0.075 mm sieve.	• LL of 34.0%. • PI of 4.0%. • LS of 3.0%.	• Std MDD 1.88 t/m³, OMC 14.0%. • Mod MDD 1.95 t/m³, OMC 12.0%. • Std CBR 90%, mod CBR 180%. • Water absorption, fine 8.5% and coarse 6.0%. • UCS 0.3 MPa.	• 65% DOS – 0.73% at 100% std MDD. • 70% DOS – 1.23% at 100% std MDD. • 75% DOS – 1.55% at 100% std MDD. • 80% DOS – 3.82% at 100% std MDD. • 70% DOS (mod) – 0.61% at 100% mod MDD. • 80% DOS (mod) – 0.53% at 100% mod MDD.	• 70% DOS – 0.95 mm at 100% std MDD. • 80% DOS – 4.46 mm at 100% std MDD. • XL-WT – 1.2 mm at 100% std MDD.
E	• RM003 and RM004 all compliant.	• LL of 34.6%. • PI of 4.0%. • LS of 1.6%.	• Std MDD 1.79 t/m³, OMC 13.5%. • Std CBR 90%. • Water absorption not tested. • UCS 0.2 MPa.	• Not tested.	• Not tested.
F	• RM003 and RM004 all compliant.	• LL of 33.4%. • PI of 3.6%. • LS of 1.4%.	• Std MDD 1.78 t/m³, OMC 15.0%. • Mod MDD 1.91 t/m³, OMC 13.0%. • Std CBR 60%, mod CBR 130%. • Water absorption, fine 7.5% and coarse 5.7%. • UCS 0.2 MPa.	• 65% DOS – 3.37% at 100% std MDD. • 70% DOS – 3.05% at 100% std MDD. • 75% DOS – 8.00% at 100% std MDD. • 70% DOS (mod) – 0.81% at 100% mod MDD. • 80% DOS (mod) – 0.62% at 100% mod MDD.	• 70% DOS – 4.71 mm at 100% std MDD. • 80% DOS – 14.98 mm at 100% std MDD.
G (0% glass)	• RM003 and RM004 all compliant.	• LL of 31.4%. • PI of 6.2%. • LS of 2.6%.	• Std MDD 1.92 t/m³, OMC 13.5%. • Mod MDD 2.01 t/m³, OMC 11.0%. • NC in std CBR 35%, mod CBR 190%. • Water absorption, fine 7.5% and coarse 6.1%. • UCS 0.1 MPa.	• 65% DOS – 0.89% at 100% std MDD. • 70% DOS – 2.29% at 100% std MDD. • 75% DOS – 8.00% at 100% std MDD. • 70% DOS (mod) – 0.49% at 100% mod MDD. • 80% DOS (mod) – 0.65% at 100% mod MDD.	• 70% DOS – 0.24 mm at 100% std MDD. • 80% DOS – 1.40 mm at 100% std MDD.
G (20% glass)	• RM003 and RM004 all compliant.	• LL of 30.4%. • PI of 4.6%. • LS of 2.2%.	• Std MDD 1.92 t/m³, OMC 13.0%. • Mod MDD 2.01 t/m³, OMC 10.5%. • Std CBR 60%, mod CBR 160%. • Water absorption, fine 4.6% and coarse 6.0%. • UCS 0.1 MPa.	• 65% DOS – 0.67% at 100% std MDD. • 70% DOS – 0.82% at 100% std MDD. • 75% DOS – 1.07% at 100% std MDD. • 80% DOS – 1.15% at 100% std MDD. • 70% DOS (mod) – 0.77% at 100% mod MDD. • 80% DOS (mod) – 0.78% at 100% mod MDD.	• 70% DOS – 0.90 mm at 100% std MDD. • 80% DOS – 1.25 mm at 100% std MDD.
H	• RM003 and RM004 all compliant.	• LL of 31.0%. • PI of 3.4%. • LS of 2.2%.	• Std MDD 1.83 t/m³, OMC 15.0%. • Std CBR 60%. • Water absorption not tested. • UCS 0.2 MPa.	• Not tested.	• Not tested.
I	• RM003 and RM004 all compliant.	• LL of 32.2%. • PI of 6.0%. • LS of 1.6%.	• Std MDD 1.84 t/m³, OMC 14.5%. • Std CBR 60%. • Water absorption not tested. • UCS 0.2 MPa.	• Not tested.	• Not tested.
J	• RM003 and RM004 all compliant.	• LL of 32.8%.	• Std MDD 1.78 t/m³, OMC 18.0%.	• Not tested.	• Not tested.

Supplier	Gradings	Atterberg limits and LS	Density, CBR, water absorption and UCS	RLT permanent strain at 50 000 cycles (%)	Wheel tracker surface deformation (mm)
		• PI of 5.0%. • LS of 2.0%.	• Std CBR 80%. • Water absorption not tested. • UCS 0.2 MPa not tested.		

4 UPDATES TO MRTS05 UNBOUND PAVEMENT MATERIALS SPECIFICATIONS

MRTS05 *Unbound Pavements* (TMR 2020b) applies to the supply and construction of unbound granular pavements. In July 2020, MRTS05 was updated by TMR based on the outcomes of this research. Generally, this update combined the content of MRTS05 with MRTS35 *Recycled Materials for Pavements* (TMR 2018) to allow Type 2 materials to be seamlessly sourced from natural, quarries or recycled material suppliers provided specification limits are achieved.

The update introduces the term recycled material blend (RMB), which is any subtype 2 material with greater than 70% of the total being comprised from recycled materials and may be blended with less than or equal to 30% natural or quarried materials. Recycled material blends have different requirements to natural gravel and quarried materials for the coarse and fine components and gradings. It is important to note that as Type 2 material may be used where Type 3 materials are specified, the updated limits also apply to Type 3 materials.

The changes to MRTS05 relevant to the use of recycled materials is summarised in Table 4.1.

Table 4.1: Revision register for MRTS05

Clause number	Description of revision
2.0 Definition of terms	Added, 'Natural material may be used as a supplementary material, as an unbound material in its own right or blended with recycled materials to produce an unbound granular pavement material' to the natural gravel definition.
	Added, 'When used in relation to TMRs quarry registration system, a quarry may also include a material recycler' to the quarry definition.
	Added definitions for brick, reclaimed asphalt pavement (RAP), recycled brick, recycled concrete, recycled glass, recycled material, recycled material blend and surfacing.
4.0 Standard test methods	Added, foreign materials Q477 and unconfined compressive strength Q115 tests.
5.2.2 Material production procedure	Changed clause title from 'Aggregate production procedure' to 'Material production procedure'.
	Changed references to 'quarry' to 'supplier' and references to 'aggregate' to 'material'.
	Added procedure to manage the source recycled materials.
6.0 Supplier registration and source material assessment	Changed references to 'quarry' to 'supplier'.
	Added requirement that materials from all sources (including natural, quarried and recycled materials) shall be registered and operated in accordance with the TMR Quarry Registration System.
7.0 Material	Added, 'Type 2 material may be produced from either natural, quarried or recycled material'.
	Added, 'Type 2 material of the same subtype produced from either natural, quarried or recycled material may be used where a Type 3 material is specified'.
	Added, 'the use of a standard Type 2 or Type 3 material may not be suitable where a Type 4 material has been specified'.

Clause number	Description of revision
7.2 Type 2 unbound material	Added a table detailing the allowable constituents for each Type 2 subtype (Table 4.2).
	Added, 'A material is considered to be a recycled material blend (and shall comply with the requirements specified for recycled material blends) where more than 70% by mass of the total material is sourced from recycled materials (that is less than or equal to 30% by mass is natural or quarried material)'.
	Added, 'Where more than 30% of the total material is sourced from a natural gravel or a quarried material, the combined material (as a whole) shall comply with the specified natural gravel or quarried material requirement, including the coarse component satisfying the most stringent properties of the relevant material group listed in Table 7.2.2 (Table 4.3)'.
	Added, 'Where applicable, different requirements have been specified for recycled material blends and natural gravel/quarried materials. Where no distinction is made between recycled material blends and natural gravel/quarried materials, the requirements shall apply to both'.
	Added, coarse component requirements of recycled material blends (Table 4.3).
	Added, fine component requirements of recycled material blends (Table 4.4).
	Added, grading envelopes for recycled material blends (Table 4.5).
	Added, pH (Table 4.6) and unconfined compressive strength requirements (Table 4.7) for any subtype including recycled concrete.
	Added, foreign material limits for any subtype including recycled materials (Table 4.8).
7.3 Type 3 unbound material	Added, 'Where a Type 3 material is specified, a Type 2 material of the same subtype may be used in its place'.
	Added, 'The requirements for a Type 2 recycled material blend are also suitable for use as a Type 3 material'.
7.6 Supplementary materials	Updated, not be self-cementing or cementitious in nature '(with the exception of recycled hardened concrete which may include some unhydrated cement resulting from the crushing of the concrete, but not added, but must comply with the UCS requirements specified)'.

Table 4.2: Constituents in Type 2 materials

Subtype	Maximum limit of each constituent (% by mass of mix)					
	Natural gravel or quarried material	Recycled materials				
		Recycled concrete	RAP	Recycled brick	Recycled glass*
2.1	100	100	0	0	0
2.2	100	100	15	15	0
2.3	100	100	20	20	20
2.4	100	100	20	45	20
2.5	100	100	45	45	20

Source: TMR (2020b).

Table 4.3: Coarse component properties – Type 2 (Recycled material blend)

Property	Subtype	Material group
		Recycled material blend
Wet strength (kN)	2.1	≥ 85
	2.2	≥ 85
	2.3	≥ 70
	2.4	≥ 70
	2.5	–
Wet/dry strength variation (%)	2.1	≤ 35
	2.2	≤
	2.3	≤

Property	Subtype	Material group
		Recycled material blend
	2.4	≤
	2.5	–
Degradation factor	2.1, 2.2	–
	2.3, 2.4	–
	2.5	–
Flakiness index general (%)	2.1, 2.2	≤ 35
	2.3, 2.4	≤ 40
	2.5	–
Water absorption (%)	2.1, 2.2	–
	2.3, 2.4	–
	2.5	–

Source: TMR (2020b).

Table 4.4: Fines component properties – Type 2 (recycled material blends)

Property	Subtype (recycled material blend)				
	2.1	2.2	2.3	2.4	2.5
Liquid limit (%)	≤ 35	≤ 35	≤ 35	≤ 40	≤ 40
Linear shrinkage (%)	1.0 – 3.5	1.0 – 3.5	1.5 – 4.5	1.5 – 6.5	1.5 – 7.5
Weighted linear shrinkage (%)	≤ 85	≤ 85	≤ 110	≤ 195	–

Source: TMR (2020a).

Table 4.5: Grading envelopes – Type 2 (recycled material blends)

Subtypes	2.1 and 2.2	2.3 and 2.4	2.5
Test sieve size (mm)	% Percent passing by mass		
75.0	–	–	–
26.5	100	100	100
19	95 – 100	95 – 100	84 – 100
13.2	78 – 92	75 – 95	69 – 95
9.5	63 – 83	60 – 90	56 – 90
4.75	44 – 64	42 – 76	37 – 77
2.36	30 – 48	28 – 60	23 – 63
0.425	13 – 21	10 – 28	8 – 30
0.075	5 – 11	3 – 11	2 – 14

Source: TMR (2020b).

Table 4.6: pH of Type 2 material containing recycled concrete

Property	Maximum value
pH	11

Source: TMR (2020b).

Table 4.7: Unconfined compressive strength of Type 2 material containing recycled concrete

Property	Maximum value	Time for UCS test
UCS	0.7 MPa	7 days

Source: TMR (2020b).

Table 4.8: Limits of foreign materials in Type 2 material containing recycled materials

Foreign material	Test method	Subtype	Maximum percent in mix (% by mass)
Brick	Q477	2.1	1.0
Asphalt		2.1	1.0
Metal, ceramics and slag (other than blast furnace slag)		All	3.0
Plaster, clay lumps and other friable material		All	1.0
Rubber, plastic, bitumen not part of asphalt, paper, cloth, paint, wood and other vegetable matter		All	0.2
Asbestos	Not permitted		

Source: TMR (2020b).

5 SUMMARY AND RECOMMENDATIONS

Year 2 of this project aimed to facilitate the increased use of recycled materials in unbound pavements by assessing the performance of several recycled pavement materials sourced from various suppliers in Queensland and updating TMR specifications. Material assessment was undertaken through laboratory evaluation using both the TMR Bulwer Island and the ARRB Melbourne laboratories.

From this report, the key findings may be summarised:

- RM001 and RM003 materials produced by recycled material suppliers in Queensland generally meet the requirements of MRTS05 although there are noted issues with high LL values and achieving the required PSD fines content.
- Samples compacted using modified compaction show significantly increased CBR values compared to those prepared using standard compaction for both RM001 and RM003 materials.
- RLT permanent strain results showed that when prepared at standard MDD, RM001 and RM003 materials generally did not exceed a permanent strain of 4.0% at 80% DOS. Additionally, no sample prepared at modified MDD exceeded a permanent strain of 1.0% at 70% DOS or 80% DOS. It is recommended that RM001 and RM003 materials have a maximum DOS of 70%. RLT testing showed that RM001 and RM003 generally performed better than equivalent natural quarried material.
- RLT permanent strain results for the RM003 mix with 20% glass, showed improved performance. RLT prepared at standard MDD with 20% glass exhibited significantly better results than the 0% glass mix (with the standard MDD for 50 000 cycles; 20% glass mix gave low strains of 1.2% at both 75% DOS and 80% DOS, whereas 0% glass mix gave a higher strain of 8% at 75% DOS).
- Wheel tracker results indicated that both RM001 and RM003 materials generally demonstrate good performance at 70% DOS whereas the 80% DOS performance showed greater variability. These results generally conformed to the 2.5 mm indicative acceptance criteria.
- The performance of the RM001 materials determined using the XL-WT indicates that the representation of in-situ performance of the materials from the three suppliers tested (Supplier B, Supplier C and Supplier D) may correlate to the RLT results. It was observed through comparisons with natural quarried material results that RM001 materials exhibited much lower deformation values at similar moisture contents.
- Including up to 20% glass to a recycled material mix has the potential to improve mix characterisation properties and performance measured using the wheel tracker and RLT test, although based on the comparison of material from only one supplier.
- Material characterisation and performance assessment of RM001 and RM003 materials indicates these materials may be used as an alternative to natural quarried materials, showing improved performance with lower MDD. This indicates less required tonnage required to build the same pavement with better in situ performance, leading to cost savings for TMR.
- These findings have been implemented into an update to MRTS05 to provide a single specification for the supply of natural, quarried and recycled materials. This specification gives the Contractor the option to use recycled materials in suitable applications and is aimed to remove the incorrect perception that recycled materials are inferior to quarried materials.

Recommendations for the third year of this project includes:

- Disseminating research outcomes by conducting knowledge transfer workshops/webinars for industry and internal stakeholders to consult the specification changes.
- Consult with TMR districts for demonstration project opportunities and assist with the monitoring and surveillance of these projects to help address any issues where recycled materials are being considered.

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APPENDIX A XL-WT TEST REPORT

This report presents the wheel-tracking test results of three recycled materials, sourced from three recycled material suppliers (Supplier B, Supplier C and Supplier D) for performance assessment. The unbound materials were tested at a 75% degree of saturation (DoS), with a wheel force of 8kN, for 40,000 tracking cycles. The samples were homogenised prior to testing, by the Department of Transport and Main Roads (TMR). The ARRB sample numbers of each material are listed in Table A.1.

A.1 MATERIAL CHARACTERISTICS

The material characteristics provided with the materials, by TMR, are seen in Appendix D. The key material parameters for the assessment of the permanent deformation in the wheel-tracking test are the maximum dry density (MDD) and the optimum moisture content (OMC) determined under standard (or modified) Proctor compaction are summarised in Table A.1. The MDD and OMC were determined in accordance with TMR test method Q142A (TMR 2020).

Table A.1: Density and moisture data of materials used (standard Proctor compaction)

Material	Sample no.	Standard MDD (t/m^3)	Standard OMC (%)
Supplier B	6437	1.81	15.5
Supplier C	6438	1.91	14.0
Supplier D	6439	1.88	14.0

A.2 TESTING PROGRAM

The testing program is based on the assessment of the permanent deformation of the crushed concrete material at 75% DoS, with a targeted dry density (DD) of 100% of the standard MDD. The test parameters were selected by TMR and testing and material conditions are defined in Table A.2.

Table A.2: Test parameters

<table>
<tr><th rowspan="2">Supplier</th><th rowspan="2">Sample no.</th><th rowspan="2">Slab no.</th><th rowspan="2">Thickness (mm)</th><th colspan="2">Compaction parameters</th><th colspan="2">Moisture conditions</th><th rowspan="2">Moisture correction* (%)</th><th rowspan="2">Wheel force (kN)</th><th rowspan="2">Tracking (cycles)</th></tr>
<tr><th>Target DD (t/m^3)</th><th>DD/MDD std (%)</th><th>Target MC (%)</th><th>DOS (%)</th></tr>
<tr><td>B</td><td>6437</td><td>6546</td><td>300</td><td>1.81</td><td>100</td><td>13.0</td><td>75</td><td>+0.20</td><td>8</td><td>40 000</td></tr>
<tr><td>C</td><td>6438</td><td>6485</td><td>300</td><td>1.91</td><td>100</td><td>11.0</td><td>75</td><td>+0.20</td><td>8</td><td>40 000</td></tr>
<tr><td>D</td><td>6439</td><td>6448</td><td>300</td><td>1.88</td><td>100</td><td>11.2</td><td>75</td><td>+0.20</td><td>8</td><td>40 000</td></tr>
</table>

**Additional moisture incorporated at the material preparation to cater for evaporation through the preparation and wheel-tracking process.*

To prepare for the test, the component materials were oven dried to constant weight at 85°C. The required water was added to reach the defined moisture content during 3 batch mixes in a planetary mixer. Moisture samples were taken after the mixing process and adjustments to the moisture content were made based on these. The sample preparation and the wheel-tracking testing were performed in accordance with Austroads Test Method AGPT/T054 *Determination of permanent deformation characteristics of unbound granular materials by the wheel-tracking* (Austroads 2015). An improved compaction procedure was used to prepare the specimen, as discussed in Section B.1.

The deformation characteristics of the materials were assessed under standard loading of 8 kN (pneumatic tyres) for 40 000 cycles (equivalent to 80 000 load passes both ways) as detailed in Table A.2.

A.3 WHEEL CONTACT STRESS

The tyre pressure is checked before testing and adjusted to 600 kPa if necessary. A wheel print analysis was undertaken to establish the average contact stress for the wheel-tracking tyre. As per the test method, the average imprint dimensions are 100 ± 5 mm wide and 170 ± 5 mm long for an 8 kN load where the actual print dimensions are summarised in Table A.3 and wheel print images may be found in Appendix E.

The calculated average contact stress under 8 kN is 617 kPa; within a close range to the standard reference test conditions of an average contact stress of 637 ± 5 kPa provided in Austroads Test Method AGPT/T054 *Determination of permanent deformation characteristics of unbound granular materials by the wheel-tracking* (Austroads 2015).

Table A.3: Tyre pressure results

Contact point	Load (kN)	Print dimensions		Estimated elliptical surface (mm^2)	Average contact stress (kPa)
		Length (mm)	Width (mm)		
0°	7.96	172	94	12 698	627
90°	7.97	173	96	13 044	611
180°	8.01	170	97	12 951	618
270°	8.1	174	97	13 256	611
Mean	8.01	172	96	12 987	617

APPENDIX B TEST RESULTS

B.1 MATERIAL PREPARATION AND COMPACTION

Before compaction, the moisture was controlled to ensure the material was at the appropriate target conditions. The results are summarised in Table B.1, showing that the material moisture contents were within the tolerance of ± 0.2%.

Table B.1: Moisture content after mixing

Supplier	Target mixing MC (%)	Post-mixing moisture content (%)			
		Batch 1	Batch 2	Batch 3	Mean
B	13.23	13.29	13.24	13.23	13.25
C	11.17	11.35	11.17	11.09	11.20
D	11.40	11.36	11.33	11.43	11.37

The compaction was undertaken in six 50 mm layers. For each layer, the vertical compaction force was applied in displacement control sequences. For each elementary layer, the vertical force applied to the compaction foot is increased gradually to reach the target height of 50 mm. The sequence is repeated six times to build the 300 mm thick material slab. A two-part epoxy was applied to the surface of the compacted material to minimize any potential moisture loss through wheel-tracking.

B.2 WHEEL-TRACKING RESULTS

Deformation of the sample surface is recorded using an automated laser which measures the height of the sample surface relative to a fixed datum:

- The initial profile is subtracted from the actual laser profile to calculate the deformation induced by the load at each loading cycle.
- Each deformation profile is smoothed to remove spikes from the laser readings.
- The mean deformation is calculated restricting the area of interest to the wheel-path (width = 110 mm). The data taken for the average is restricted to a transverse position between the boundaries ± 55 mm.

To provide extra information from the test, the maximum rut depth from the slab surface profile data is also calculated through an analytical process. The deformation and rut depth data for all sample slabs is presented in Section B.2.1 to Section B.2.3. Indications about the deformation and rutting rates are also provided in Appendix F and photographs of the slabs pre- and post-testing are presented in Appendix G.

B.2.1 SUPPLIER B

The deformation and rut depth data for Supplier B is presented in Table B.2 and Table B.3 and plotted in Figure B.1.

Table B.2: Supplier B overall mean surface deformation data

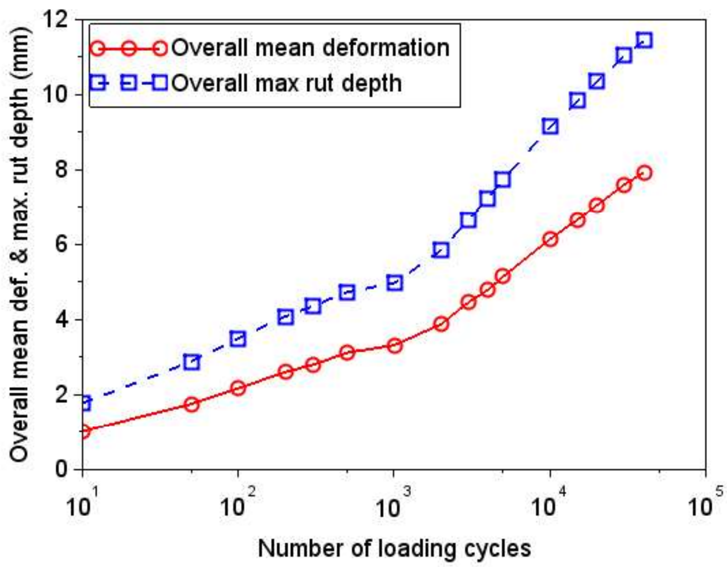
Number of cycles N	Cross-section					Mean overall (mm)
	X = -150 mm	X = -75 mm	X = +0 mm	X = +75 mm	X = +150 mm	
0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.9	0.9	0.7	1.1	1.3	1.0
50	1.6	1.7	1.5	1.9	2.0	1.7
100	2.0	2.1	2.0	2.3	2.4	2.2
200	2.4	2.6	2.5	2.7	2.9	2.6
300	2.6	2.6	2.8	2.9	3.1	2.8

Number of cycles N	Cross-section					Mean overall (mm)
	X = -150 mm	X = -75 mm	X = +0 mm	X = +75 mm	X = +150 mm	
500	2.9	2.8	3.2	3.3	3.4	3.1
1000	3.3	3.0	3.4	3.4	3.5	3.3
2000	3.7	3.5	3.7	4.1	4.4	3.9
3000	4.0	4.1	4.4	4.9	4.9	4.5
4000	4.4	4.6	4.7	5.2	5.2	4.8
5000	4.6	5.0	5.1	5.5	5.4	5.1
10000	5.4	6.0	6.3	6.6	6.3	6.1
15000	5.9	6.6	6.8	7.2	6.9	6.7
20000	6.4	7.0	7.2	7.6	7.3	7.1
30000	6.9	7.6	7.7	8.1	7.7	7.6
40000	7.1	8.1	7.9	8.4	8.0	7.9

Table B.3: Supplier B overall maximum rut depth data

Number of cycles N	Cross-section					Mean overall (mm)
	X = -150 mm	X = -75 mm	X = +0 mm	X = +75 mm	X = +150 mm	
0	0.0	0.0	0.0	0.0	0.0	0.0
10	1.5	1.7	1.5	1.9	2.3	1.8
50	2.4	2.8	2.9	3.0	3.3	2.9
100	3.0	3.5	3.7	3.5	3.7	3.5
200	3.5	4.2	4.4	4.0	4.3	4.1
300	3.7	4.0	4.9	4.4	4.8	4.4
500	4.1	4.1	5.5	4.9	5.1	4.7
1000	4.6	4.5	5.6	4.9	5.2	5.0
2000	5.2	5.1	6.2	5.9	6.7	5.8
3000	5.6	5.9	7.3	7.1	7.4	6.7
4000	6.3	6.7	7.8	7.7	7.8	7.2
5000	6.6	7.3	8.4	8.2	8.1	7.7
10000	7.7	8.9	10.1	9.6	9.4	9.2
15000	8.5	9.6	10.7	10.4	10.1	9.8
20000	8.9	10.1	11.3	11.0	10.5	10.4
30000	9.6	10.9	11.8	11.7	11.1	11.0
40000	9.9	11.4	12.2	12.1	11.5	11.4

Figure B.1 Supplier B overall mean surface deformation data and maximum rut depth data



B.2.2 SUPPLIER C

The deformation and rut depth data for Supplier C is presented in Table B.4 and Table B.5 and plotted in Figure B.2.

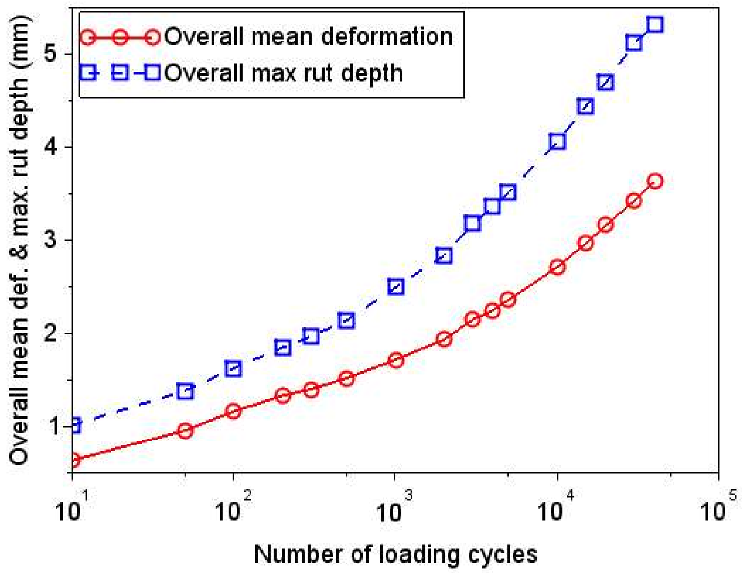
Table B.4: Supplier C overall mean surface deformation data

Number of cycles N	Cross-section					Mean overall (mm)
	X = -150 mm	X = -75 mm	X = +0 mm	X = +75 mm	X = +150 mm	
0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.7	0.6	0.4	0.7	0.7	0.6
50	1.0	1.0	0.7	1.0	1.1	1.0
100	1.1	1.1	0.9	1.2	1.6	1.2
200	1.2	1.2	1.0	1.4	1.9	1.3
300	1.2	1.3	1.1	1.4	2.0	1.4
500	1.3	1.4	1.2	1.6	2.0	1.5
1 000	1.5	1.6	1.5	1.8	2.2	1.7
2 000	1.7	1.8	1.8	2.1	2.3	1.9
3 000	1.8	2.0	2.0	2.4	2.6	2.1
4 000	1.9	2.1	2.1	2.4	2.7	2.2
5 000	2.0	2.2	2.2	2.6	2.8	2.4
10 000	2.2	2.6	2.7	2.9	3.1	2.7
15 000	2.4	2.8	3.0	3.2	3.4	3.0
20 000	2.5	3.0	3.2	3.5	3.6	3.2
30 000	2.7	3.3	3.5	3.7	3.8	3.4
40 000	2.8	3.5	3.8	4.0	4.0	3.6

Table B.5: Supplier C overall maximum rut depth data

Number of cycles N	Cross-section					Mean overall (mm)
	X = -150 mm	X = -75 mm	X = +0 mm	X = +75 mm	X = +150 mm	
0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.8	1.0	0.9	1.2	1.1	1.0
50	1.2	1.4	1.3	1.7	1.3	1.4
100	1.4	1.7	1.6	2.0	1.6	1.6
200	1.6	1.8	1.8	2.3	1.7	1.8
300	1.6	1.9	2.0	2.4	1.9	2.0
500	1.7	2.1	2.1	2.7	2.0	2.1
1 000	2.0	2.4	2.6	3.1	2.4	2.5
2 000	2.2	2.8	3.1	3.5	2.6	2.8
3 000	2.4	3.1	3.4	3.9	3.0	3.2
4 000	2.7	3.3	3.6	4.2	3.1	3.4
5 000	2.7	3.4	3.9	4.3	3.3	3.5
10 000	3.1	3.9	4.5	5.0	3.8	4.1
15 000	3.4	4.4	4.9	5.3	4.2	4.4
20 000	3.6	4.6	5.2	5.6	4.5	4.7
30 000	3.9	5.0	5.8	6.0	4.9	5.1
40 000	4.0	5.3	5.9	6.4	5.0	5.3

Figure B.2 Supplier C overall mean surface deformation data and maximum rut depth data



B.2.3 SUPPLIER D

The deformation and rut depth data for Supplier D is presented in Table B.6 and Table B.7 and plotted in Figure B.3.

Table B.6: Supplier D overall mean surface deformation data

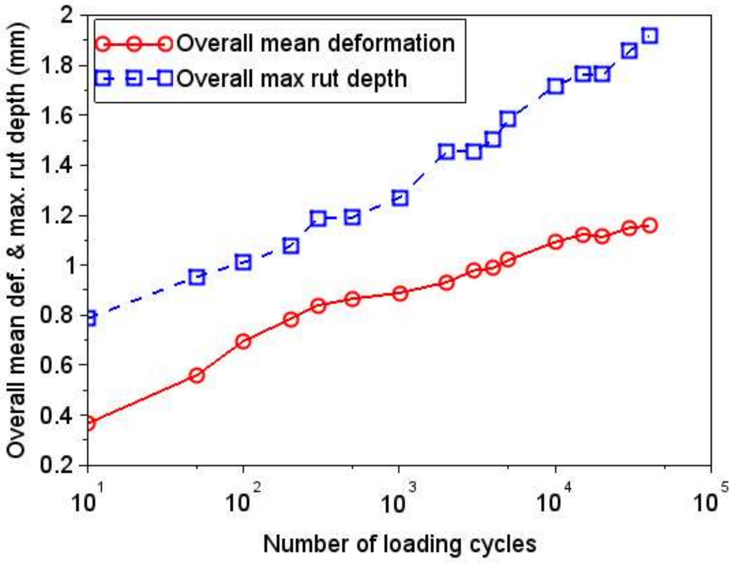
Number of cycles N	Cross-section					Mean overall (mm)
	X = -150 mm	X = -75 mm	X = +0 mm	X = +75 mm	X = +150 mm	
0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.5	0.5	0.4	0.2	0.4	0.4
50	0.6	0.7	0.5	0.5	0.5	0.6
100	0.8	0.8	0.6	0.7	0.5	0.7
200	0.8	0.9	0.8	0.7	0.7	0.8
300	0.9	1.0	0.8	0.8	0.7	0.8
500	0.9	1.0	0.9	0.8	0.7	0.9
1 000	0.9	1.0	0.9	0.8	0.8	0.9
2 000	1.0	1.0	0.9	0.9	0.8	0.9
3 000	1.0	1.1	0.9	1.1	0.9	1.0
4 000	1.0	1.1	0.9	1.1	0.9	1.0
5 000	1.0	1.1	1.0	1.1	0.9	1.0
10 000	1.0	1.2	1.1	1.1	1.1	1.1
15 000	1.1	1.3	0.9	1.2	1.1	1.1
20 000	1.1	1.3	0.7	1.3	1.1	1.1
30 000	1.2	1.4	0.6	1.4	1.2	1.2
40 000	1.2	1.4	0.5	1.4	1.2	1.2

Table B.7: Supplier D overall maximum rut depth data

Number of cycles N	Cross-section					Mean overall (mm)
	X = -150 mm	X = -75 mm	X = +0 mm	X = +75 mm	X = +150 mm	
0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.8	0.8	0.8	0.7	0.8	0.8
50	0.9	1.0	0.9	0.9	1.0	1.0
100	1.0	1.1	1.0	0.9	1.1	1.0
200	1.0	1.1	1.1	1.1	1.2	1.1
300	1.1	1.3	1.2	1.1	1.4	1.2
500	1.1	1.2	1.3	1.2	1.3	1.2
1 000	1.1	1.3	1.3	1.2	1.4	1.3
2 000	1.2	1.4	1.7	1.4	1.6	1.5
3 000	1.3	1.4	1.5	1.4	1.6	1.5
4 000	1.4	1.4	1.6	1.4	1.7	1.5
5 000	1.3	1.5	1.7	1.5	1.9	1.6
10 000	1.5	1.6	1.9	1.8	1.9	1.7
15 000	1.6	1.8	1.4*	1.9	2.2	1.8
20 000	1.8	1.9	1.0*	1.9	2.2	1.8
30 000	1.9	1.9	1.0*	2.0	2.4	1.9
40 000	1.8	2.1	1.2*	2.1	2.4	1.9

** Sealing membrane delamination*

Figure B.3 Supplier D overall mean surface deformation data and maximum rut depth data



B.3 POST-WHEEL TRACKING INVESTIGATION

B.3.1 POST-WHEEL TRACKING MOISTURE CONTENT

Two sets of moisture samples were extracted from each slab during testing to identify potential changes in the moisture content of the slabs. Nine samples were taken from the top 100 mm and nine from the bottom 100 mm of each specimen as shown in Figure B.4. The moisture content results are shown in Table B.8 and Table B.9.

Figure B.4 Schematic view of the moisture sampling pattern

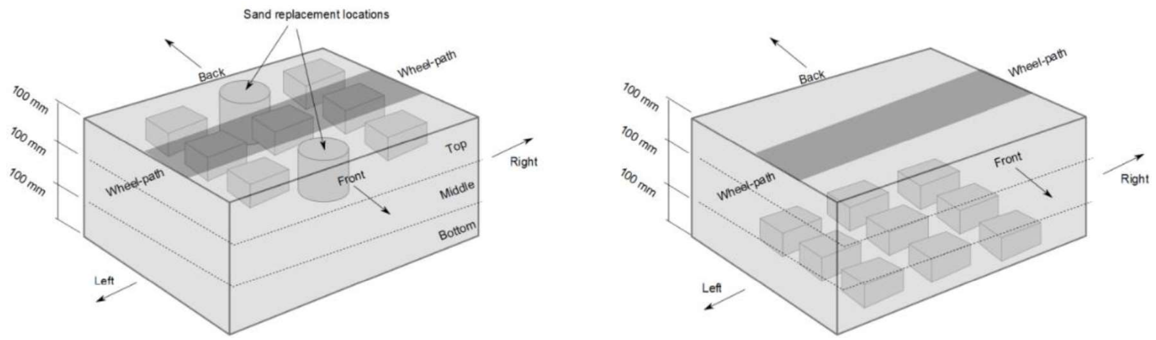


Table B.8: Measured post-wheel tracking moisture content – top 100 mm

Sample no.	Target MC (%)	Prep MC	Front side				Wheel-path				Back side				Sides average
			Left	Centre	Right	Average	Left	Centre	Right	Average	Left	Centre	Right	Average	
B	13.0	13.3	12.50	12.60	12.40	12.50	12.40	12.70	12.40	12.50	12.80	13.20	13.00	13.00	12.75
C	11.0	11.2	10.00	11.00	10.50	10.50	10.60	11.20	10.46	10.75	10.80	10.80	10.50	10.70	10.60
D	11.2	11.4	11.00	11.20	11.06	11.09	10.10	11.60	10.90	10.87	10.70	10.80	10.90	10.80	10.94

Table B.9: Measured post-wheel tracking moisture content – bottom 100 mm

Sample no.	Target MC (%)	Prep MC	Front side				Wheel-path				Back side				Sides average
			Left	Centre	Right	Average	Left	Centre	Right	Average	Left	Centre	Right	Average	
B	13.0	13.3	12.90	13.40	13.10	13.13	13.50	13.50	13.70	13.57	13.30	13.10	12.70	13.03	13.08
C	11.0	11.2	10.90	10.90	10.90	10.90	11.20	11.30	11.20	11.23	10.90	11.00	10.80	10.90	10.90
D	11.2	11.4	10.60	11.60	11.30	11.17	11.00	11.50	11.40	11.30	10.50	10.50	10.90	10.63	10.90

B.3.2 DENSITY TESTING

The final slab density was measured using the sand replacement method in two locations, taken on both sides of the wheel path located at the centre of the slab as shown in Figure B.4**Error! Reference source not found.** and the results are summarised in Table B.10. The sand replacement density provides an estimate on the actual dry density of the slab specimen, however, density data may be affected by material heaving on the sides of the wheel-path.

Table B.10: Measured dry density (sand replacement method)

Supplier	Target DD (t/m³)	Sand replacement DD (t/m³)			Relative DD/DD$_{target}$ (%)
		Front	Back	Mean	
B	1.81	1.83	1.75	1.79	98.90
C	1.91	1.90	1.83	1.86	97.61
D	1.88	1.89	1.85	1.87	99.63

B.3.3 ACTUAL TESTING CONDITIONS

The actual density and moisture content conditions (Table B.11) are defined as follows:

- The actual density is the average density measured from sand replacement testing on the two samples centred in the un-trafficked area.
- The actual moisture content considered for the test is the average moisture from the seven moisture samples extracted from the top 100 mm of the slab after testing.

Table B.11: Actual testing conditions

Sample no.	Dry density (DD)			Moisture content (MC)		Degree of saturation (DOS)	
	Target DD (t/m³)	Actual DD (t/m³)	DD/MDD std (%)	Target MC (%)	Actual MC (%)	Target DOS	Actual DOS* (%)
B	1.81	1.79	99	13.0	12.8	75	75.2
C	1.91	1.86	98	11.0	10.6	75	72.3
D	1.88	1.87	100	11.2	10.9	75	73.8

** Degree of saturation calculated based on the target density and the actual moisture*

B.3.4 POST WHEEL-TRACKING PSD

Particle size distribution (PSD) testing was performed on samples extracted from the slabs underneath the wheel-path and the results for each supplier are presented in each of the following sections.

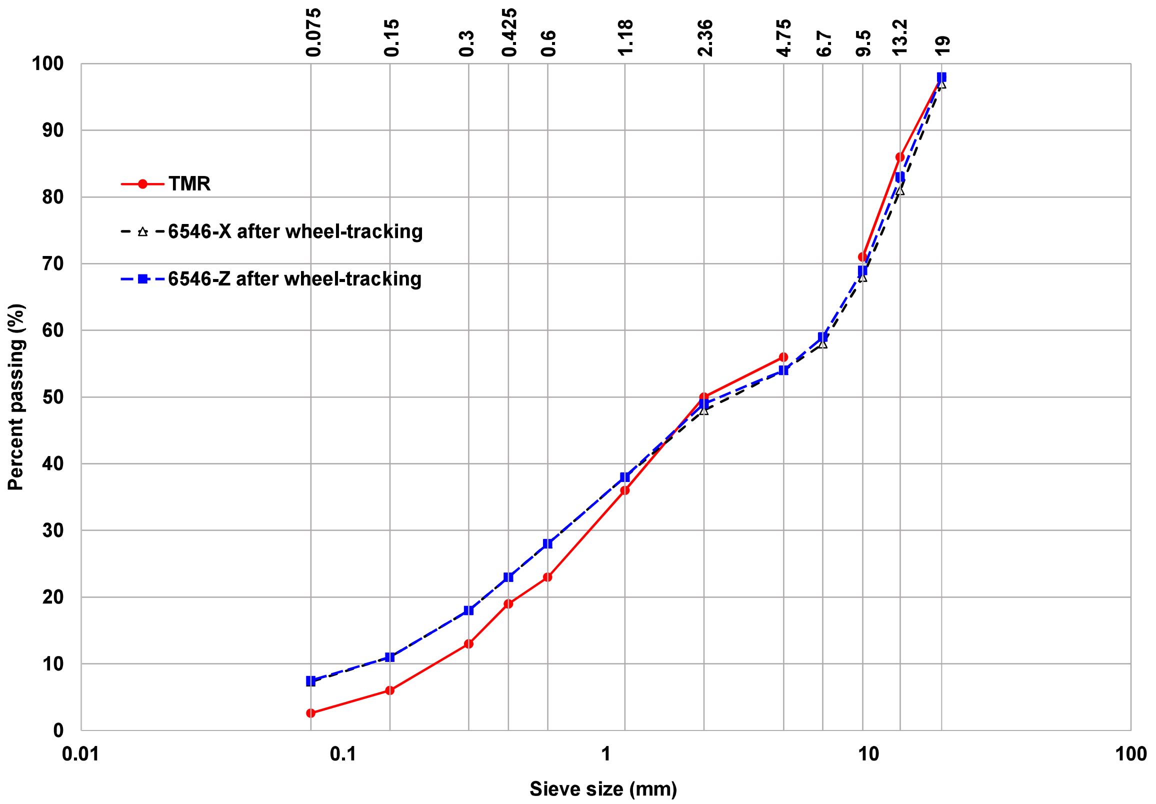
Supplier B

The PSD results from Supplier B pre- and post-WT testing are summarised in Table B.12 and depicted in Figure B.5. This shows some breakdown of particles in the sieve sizes smaller than 1.18mm, showing up to a 5% increase in material passing.

Table B.12: Supplier B pre and post-testing PSD data

Sieve size (mm)	Percentage passing (%)		
	Pre-testing	Post-WT testing	
		6546-X	6546-Z
19	98	97	98
13.2	86	81	83
9.5	71	68	69
6.7	-	58	59
4.75	56	54	54
2.36	50	48	49
1.18	36	38	38
0.6	23	28	28
0.425	19	23	23
0.3	13	18	18
0.15	6	11	11
0.075	2.6	7.3	7.5

Figure B.5 Supplier B grading curves pre- and post-WT



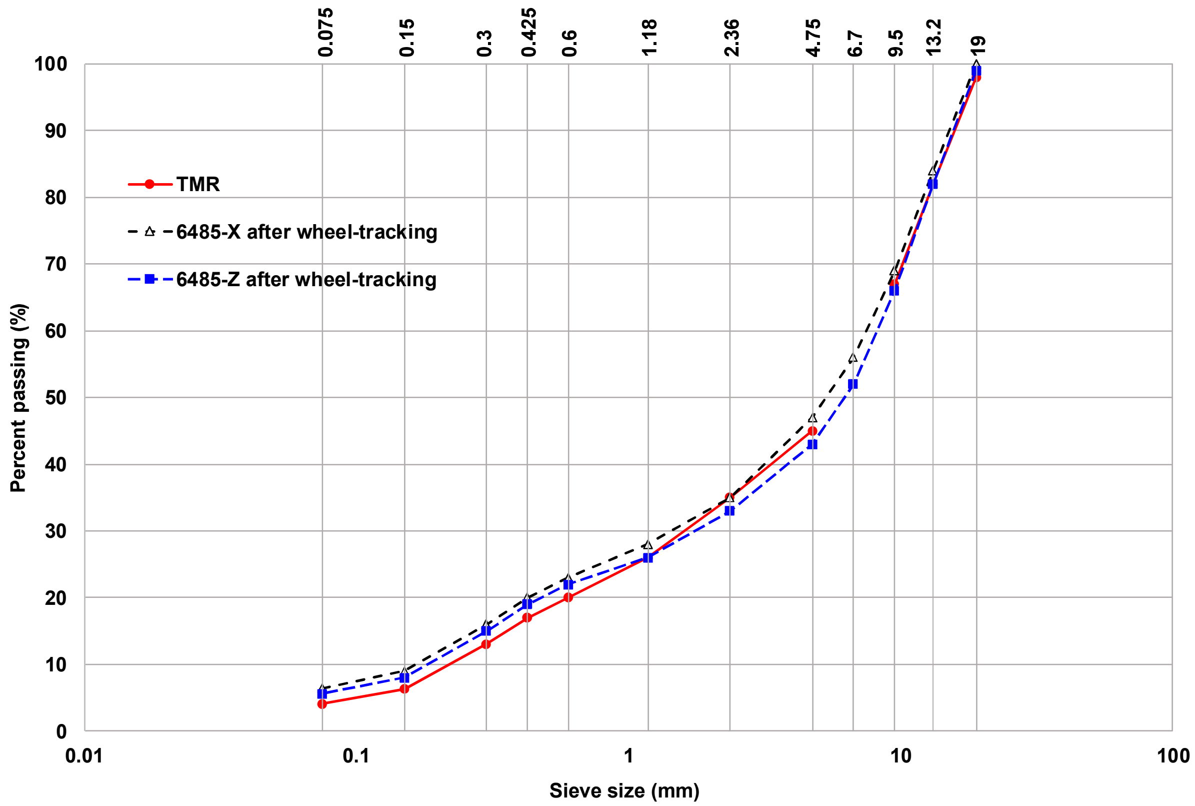
Supplier C

Supplier C PSD results pre- and post-WT testing are summarised in Table B.13 and depicted in Figure B.6. Notably, the Supplier C materials showed little particle breakdown (< 3%) post-WT testing.

Table B.13: Supplier C PSD data

Sieve size (mm)	Percentage passing (%)		
	Pre-testing	Post-WT testing	
		6485-X	6485-Z
19	98	100	99
13.2	82	84	82
9.5	67	69	66
6.7	-	56	52
4.75	45	47	43
2.36	35	35	33
1.18	26	28	26
0.6	20	23	22
0.425	17	20	19
0.3	13	16	15
0.15	6.3	9	8
0.075	4.1	6.4	5.6

Figure B.6 Supplier C grading curves pre- and post-WT



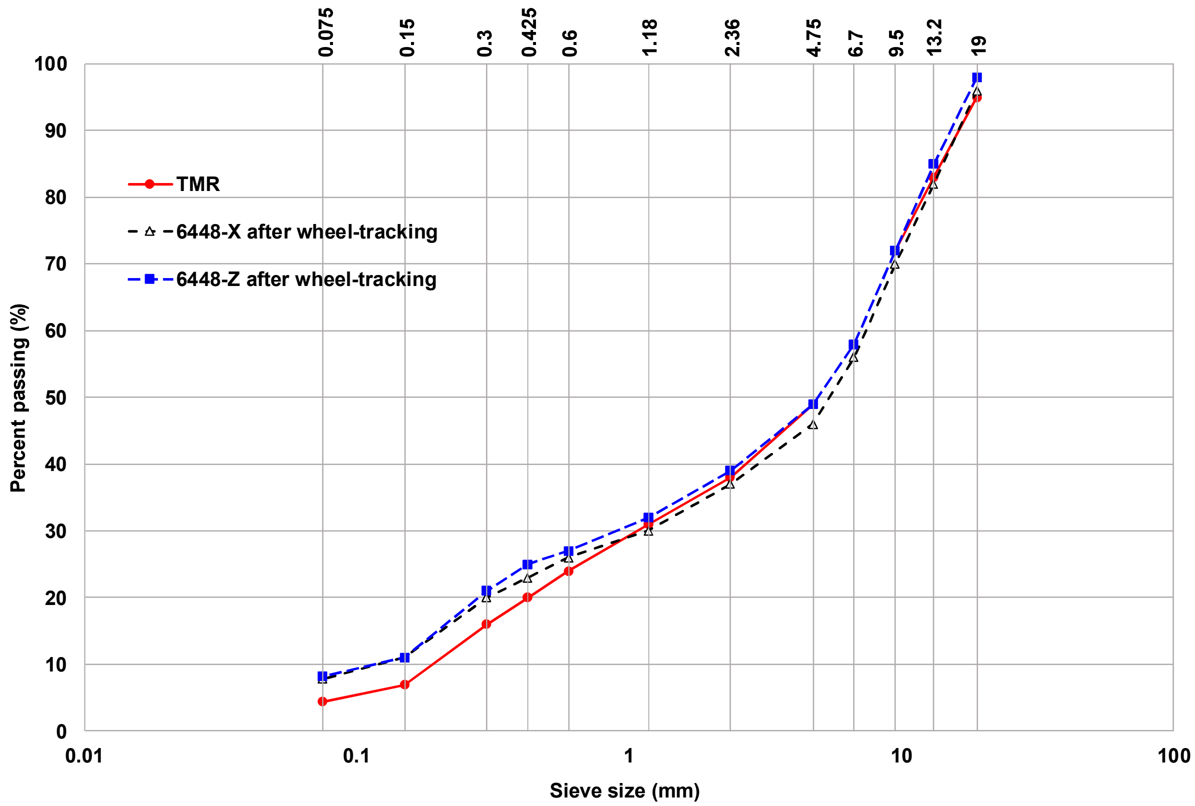
Supplier D

The PSD results from Supplier D pre- and post-WT testing are summarised in Table B.14 and depicted in Figure B.7. This shows up to 4% breakdown in the smaller sieve sizes, from 0.425-0.075 mm.

Table B.14: Supplier D PSD data

Sieve size (mm)	Percentage passing (%)		
	Pre-testing	Post-WT testing	
		6448-X	6448-Z
19	95	96	98
13.2	83	82	85
9.5	72	70	72
6.7	-	56	58
4.75	49	46	49
2.36	38	37	39
1.18	31	30	32
0.6	24	26	27
0.425	20	23	25
0.3	16	20	21
0.15	6.9	11	11
0.075	4.4	7.8	8.2

Figure B.7 Supplier D grading curves pre- and post-WT



APPENDIX C TESTING SUMMARY

The specimens have been prepared and tested according to the wheel-tracking testing procedures for unbound granular materials developed for Austroads (2013a; 2013b). The target and actual testing conditions, as well as the WT results are summarised in Table C.1. Additionally, the three recycled material surface deformation and rutting performance results are presented in

Figure C.1 and Figure C.2, respectively.

Table C.1: Wheel-tracking test summary table

Supplier	Dry density (DD)			Moisture content (MC)			WT results			
	Target DD (t/m^3)	Actual DD (t/m^3)	DD/MDD std (%)	Target (%)	Actual (%)	DOS (%)	Mean surface deformation (mm)		Maximum rut depth (mm)	
							100 cycles	40 000 cycles	100 cycles	40 000 cycles
B	1.81	1.79	99	13.0	12.8	75	2.2	7.9	3.5	11.4
C	1.91	1.86	98	11.0	10.6	72	1.2	3.6	1.6	5.3
D	1.88	1.87	100	11.2	10.9	74	0.7	1.2	1.0	1.9

Figure C.1: Mean surface deformation summary

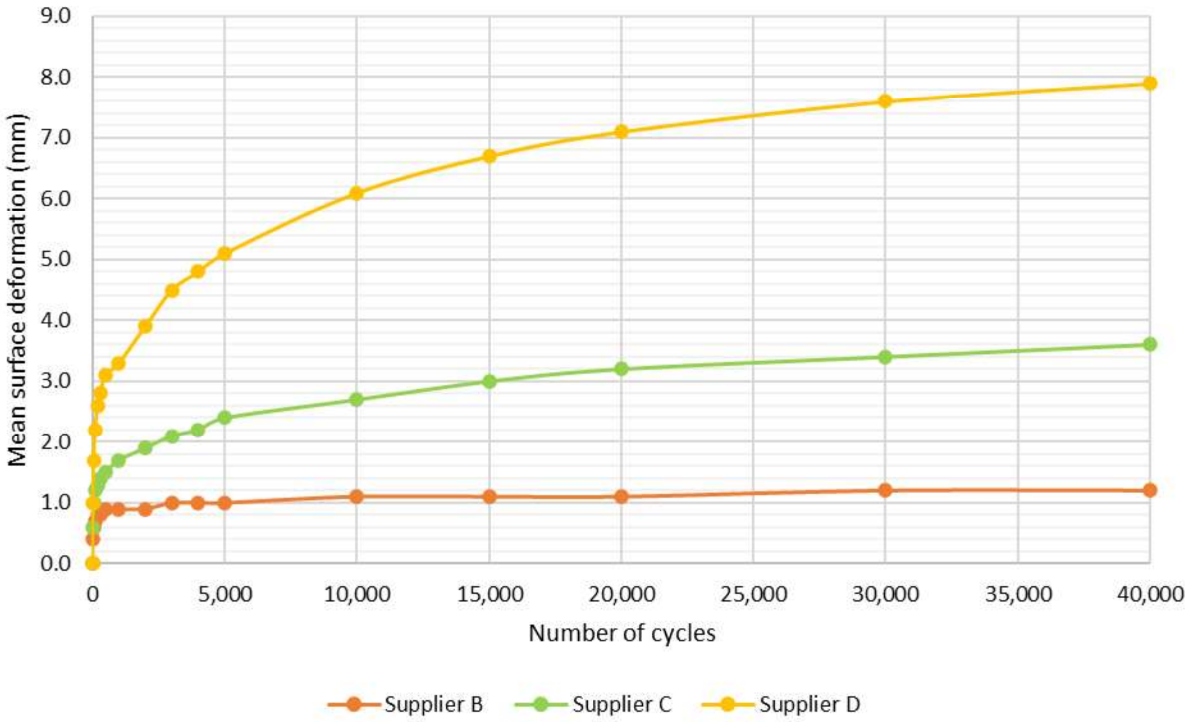
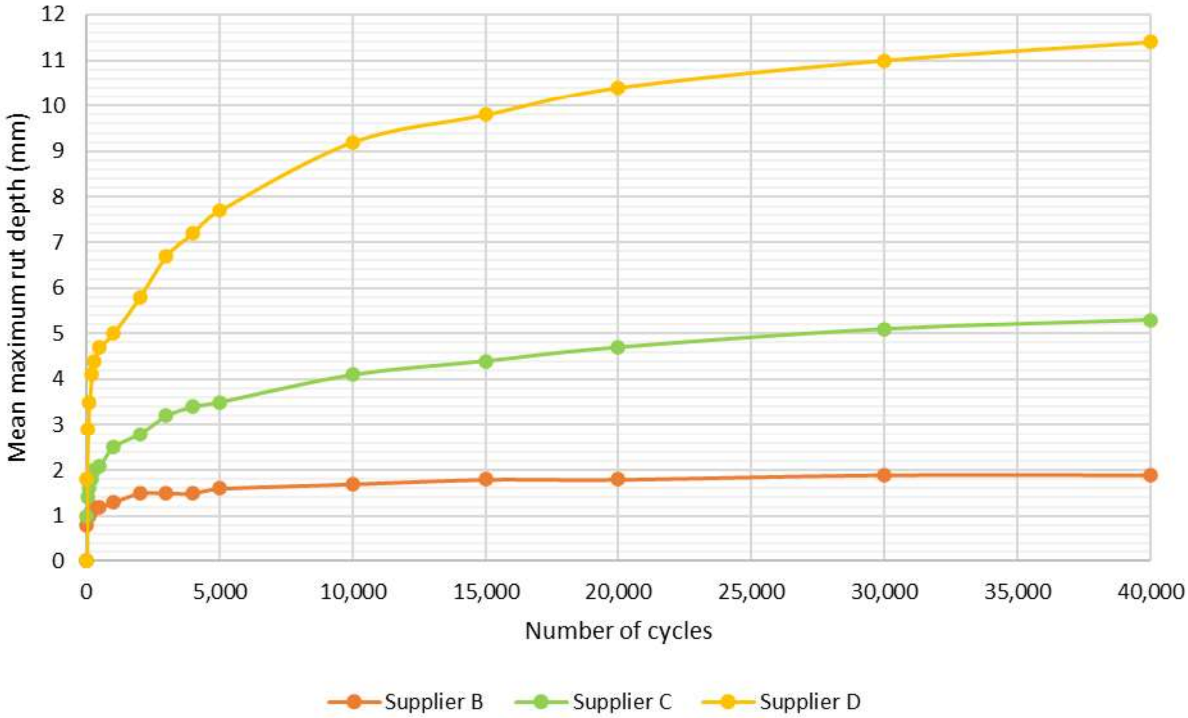


Figure C.2: Mean maximum rut depth summary



APPENDIX D INFORMATION PROVIDED WITH MATERIAL SAMPLE

D.1 SUPPLIER B

Figure D.1: Supplier B materials test report page 1

Queensland Government

Materials Test Report

Materials Services - Brisbane
Department of Transport and Main Roads
Bulwer Island Laboratory
396 Tingira Street
Pinkenba, Qld, 4008

Telephone: (07) 3066 3345

Report No: MAT:BIL19W-0142-S02-1
Issue No: 4
This report replaces all previous issues of report no MAT:BIL19W-0142-S02-1.

Accredited for compliance with ISO/IEC 17025 - Testing

NATA Accredited Laboratory Number 2302

Approved Signatory: Anthony Neary (Senior Materials Technologist)
Date of Issue: 6/09/2019

THIS DOCUMENT SHALL NOT BE REPRODUCED EXCEPT IN FULL

Client: ARRB Group
21 McLachlan Street
Fortitude Valley QLD 4006

Project: NACOE P94 - RM001 Material Testing
Location:

Sample Details

Sample ID:	BIL19W-0142-S02
Sampling Method:	
Date Sampled:	
Source:	
Material:	RM001
Sampled By:	Client
Specification:	MRTS35 - Recycled Material Blends for Pavements
Location:	
Client Sample ID:	BS19/365

Other Test Results

Description	Method	Result	Limits
Apparent Particle Density of Soil [Q109]			
Apparent Particle Density (t/m³):		2.64	
Date Tested		8/07/2019	
Atterberg Limits [Q104A/Q105/Q106]			
Linear Shrinkage (%)	Q106	1.6	≤3.5
Liquid Limit (%)	Q104A	39.2	≤35
Plastic Limit (%)	Q105	36.6	
Plasticity Index (%)	Q105	2.6	
Weighted Plasticity Index (%)	Q105	49	
Weighted Linear Shrinkage (%)	Q106	30	≤85
Date Tested		16/07/2019	
Degradation Factor - Fine Aggregate [AS 1141.25.3]			
Degradation Factor		57	
Wash water clear?		Yes	
Date Tested		24/07/2019	
Degradation Factor [Q208B]			
Degradation Factor		9	
Date Tested		23/07/2019	
Flakiness Index [Q201]			
Flakiness Index (%)		4	
Date Tested		13/08/2019	
Particle Density - Coarse [Q214B]			
Apparent Particle Density (t/m³)		2.64	
Particle Density Dry (t/m³)		2.33	
Particle Density SSD (t/m³)		2.45	
Water Absorption (%)		5.0	
Revision Year 2018			
Date Tested		23/07/2019	

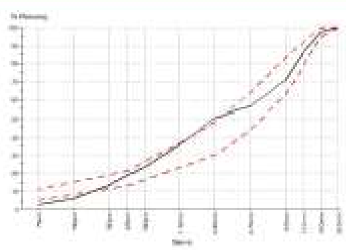
Particle Size Distribution

Method: Q103A

Date Tested: 7/07/2019

Sieve Size	% Passing	Limits
26.5mm	100	100
19.0mm	98	95 – 100
13.2mm	86	78 – 92
9.5mm	71	63 – 83
4.75mm	56	44 – 64
2.36mm	50	30 – 48
1.18mm	36	
600µm	23	
425µm	19	13 – 21
300µm	13	
150µm	6.0	
75µm	2.8	5 – 11

Chart



Comments

Sample tested as received.
Apparent Particle Density performed in accordance with Q109 (2017)
AS 1141.32 - Weak Particles performed in accordance with Q217 (2018)

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Figure D.2: Supplier B materials test report page 2

Queensland Government

Materials Test Report

Materials Services - Brisbane
Department of Transport and Main Roads
Bulwer Island Laboratory
398 Tingira Street
Pinkenba, Qld, 4008

Telephone: (07) 3066 3345

Report No: MAT:BIL19W-0142-S02-1
Issue No: 4
This report replaces all previous issues of report no MAT:BIL19W-0142-S02-1.

Client: ARRB Group
21 McLachlan Street
Fortitude Valley QLD 4006

Project: NACOE P94 - RM001 Material Testing
Location:

NATA Accredited Laboratory Number 2302
Accredited for compliance with ISO/IEC 17025 - Testing
Approved Signatory: Anthony Neary (Senior Materials Technologist)
Date of Issue: 6/09/2019
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Sample Details

Sample ID:	BIL19W-0142-S02
Sampling Method:	
Date Sampled:	
Source:	
Material:	RM001
Sampled By:	Client
Specification:	MRTS35 - Recycled Material Blends for Pavements
Location:	
Client Sample ID:	BS19/365

Other Test Results

Description	Method	Result	Limits
Particle Density - Fine [Q214A]			
Apparent Particle Density (t/m³)		2.59	
Particle Density Dry (t/m³)		2.14	
Particle Density SSD (t/m³)		2.32	
Water Absorption (%)		8.1	
Revision Year 2018			
Date Tested		6/08/2019	
Particle Size Distribution of Soil - Wet Sieving [Q103A]			
Fines Ratio		0.14	
Weak Particles [AS 1141.32]			
Weak Particles (%)		0.2	
Passing 2.36 mm Sieve (%)		52.1	
Date Tested		5/08/2019	
Wet/Dry Strength Variation [Q205ABC]			
Nominal Sample Size (mm)		20	
Nature of Sample		Crushed Rock	
Fraction Size		-13.2 + 9.5 mm	
Wet Strength (kN)		101	
Dry Strength (kN)		149	
Wet/Dry Strength Variation (%)		32	
Revision Year 2018			
Date Tested		28/08/2019	

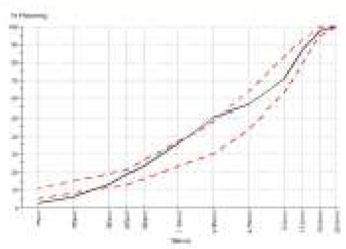
Particle Size Distribution

Method: Q103A

Date Tested: 7/07/2019

Sieve Size	% Passing	Limits
26.5mm	100	100
19.0mm	98	95 – 100
13.2mm	86	78 – 92
9.5mm	71	63 – 83
4.75mm	56	44 – 64
2.36mm	50	30 – 48
1.18mm	36	
600µm	23	
425µm	19	13 – 21
300µm	13	
150µm	6.0	
75µm	2.6	5 – 11

Chart



Comments

Sample tested as received.
Apparent Particle Density performed in accordance with Q109 (2017)
AS 1141.32 - Weak Particles performed in accordance with Q217 (2018)

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Figure D.3: Supplier B maximum dry density report

Materials Services - Brisbane
Department of Transport and Main Roads
Bulwer Island Laboratory
398 Tingira Street
Pinkenba, Qld, 4008

Telephone: (07) 3066 3345

Queensland Government

Maximum Dry Density Report

Report No: MDD:BIL19W-0142-S02-2
Issue No: 1

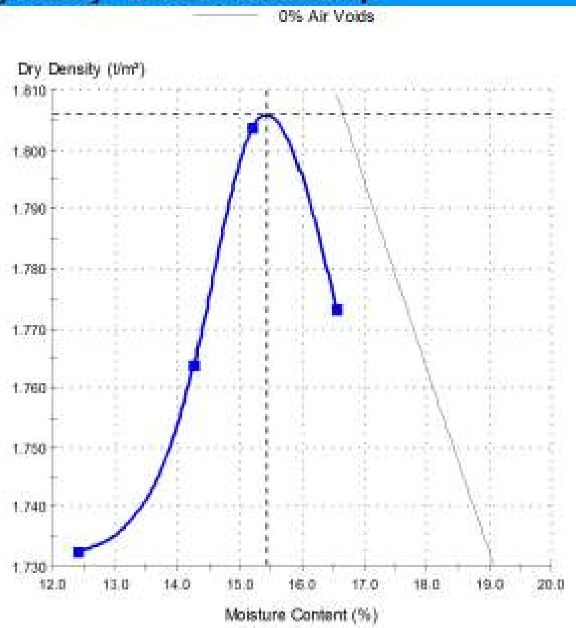
Client:	ARRB Group 21 McLachlan Street Fortitude Valley QLD 4006
Project:	NACOE P94 - RM001 Material Testing
Location:	

NATA Accredited Laboratory Number 2302
Accredited for compliance with ISO/IEC 17025 - Testing
Approved Signatory: Anthony Neary (Senior Materials Technologist)
Date of Issue: 16/08/2019
THIS DOCUMENT SHALL NOT BE REPRODUCED EXCEPT IN FULL

Sample Details

Location:			
Sample ID:	BIL19W-0142-S02	**Date Sampled:**	
Sampling Method:			
Source:		**Material:**	RM001
Specification:	MRTS35 - Recycled Material Blends for Pavements		
Location:			
Tested By:	Jason Maudsley	**Date Tested:**	11/07/2019

Dry Density - Moisture Relationship



Test Results

Maximum Dry Density - Standard [Q142A]

Standard MDD (t/m³):	1.81
Standard OMC (%):	15.5
MC Test Method:	Q102A
Oversize Sieve (mm):	
Oversize Material (%):	
Oversize % Basis:	
Curing Duration (h):	24
Plasticity Determination Method:	Q104A

Comments

Sample tested as received. BS19/365
Moisture Content performed in accordance with Q102A (2016)

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D.2 SUPPLIER C

Figure D.4: Supplier C materials test report page 1

Materials Services - Brisbane
Department of Transport and Main Roads
Bulwer Island Laboratory
398 Tingira Street
Pinkenba, Qld, 4008

Telephone: (07) 3066 3345

Queensland Government

Materials Test Report

Report No: MAT:BIL19W-0142-S03-1
Issue No: 3
This report replaces all previous issues of report no MAT:BIL19W-0142-S03-1.

Client: ARRB Group
21 McLachlan Street
Fortitude Valley QLD 4006

Project: NACOE P94 - RM001 Material Testing
Location:

Accredited for compliance with ISO/IEC 17025 - Testing

NATA Accredited Laboratory Number 2302

Approved Signatory: Anthony Neary (Senior Materials Technologist)
Date of Issue: 6/09/2019

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Sample Details

Sample ID: BIL19W-0142-S03
Sampling Method:
Date Sampled:
Source:
Material: RM001
Sampled By: Client
Specification: MRTS35 - Recycled Material Blends for Pavements
Location:
Client Sample ID: BS19/366

Other Test Results

Description	Method	Result	Limits
Apparent Particle Density of Soil [Q109]			
Apparent Particle Density (t/m³):		2.65	
Date Tested		17/07/2019	
Atterberg Limits [Q104A/Q105/Q106]			
Linear Shrinkage (%)	Q106		≤3.5
Liquid Limit (%)	Q104A	33.2	≤35
Plastic Limit (%)	Q105	30.6	
Plasticity Index (%)	Q105	2.6	
Weighted Plasticity Index (%)	Q105	43	
Date Tested		9/07/2019	
Degradation Factor - Fine Aggregate [AS 1141.25.3]			
Degradation Factor		25	
Wash water clear?		Yes	
Date Tested		24/07/2019	
Degradation Factor [Q208B]			
Degradation Factor		3	
Date Tested		23/07/2019	
Flakiness Index [Q201]			
Flakiness Index (%)		8	
Date Tested		15/08/2019	
Particle Density - Coarse [Q214B]			
Apparent Particle Density (t/m³)		2.68	
Particle Density Dry (t/m³)		2.33	
Particle Density SSD (t/m³)		2.46	
Water Absorption (%)		5.5	
Revision Year 2018			
Date Tested		24/07/2019	

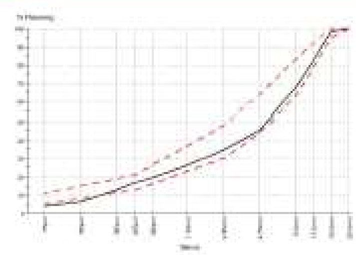
Particle Size Distribution

Method: Q103A

Date Tested: 7/07/2019

Sieve Size	% Passing	Limits
26.5mm	100	100
19.0mm	98	95 – 100
13.2mm	82	78 – 92
9.5mm	67	63 – 83
4.75mm	45	44 – 64
2.36mm	35	30 – 48
1.18mm	26	
600µm	20	
425µm	17	13 – 21
300µm	13	
150µm	6.3	
75µm	4.1	5 – 11

Chart



Comments

Sample tested as received.
Apparent Particle Density performed in accordance with Q109 (2017)
AS 1141.32 - Weak Particles performed in accordance with Q217 (2018)

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Figure D.5: Supplier B materials test report page 2

Queensland Government

Materials Test Report

Materials Services - Brisbane
Department of Transport and Main Roads
Bulwer Island Laboratory
398 Tingira Street
Pinkenba, Qld, 4008

Telephone: (07) 3066 3345

Report No: MAT:BIL19W-0142-S03-1
Issue No: 3
This report replaces all previous issues of report no MAT:BIL19W-0142-S03-1

Client: ARRB Group
21 McLachlan Street
Fortitude Valley QLD 4006

Project: NACOE P94 - RM001 Material Testing
Location:

Accredited for compliance with ISO/IEC 17025 - Testing

NATA Accredited Laboratory Number 2302

Approved Signatory: Anthony Neary (Senior Materials Technologist)
Date of Issue: 6/09/2019

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Sample Details

Sample ID: BIL19W-0142-S03
Sampling Method:
Date Sampled:
Source:
Material: RM001
Sampled By: Client
Specification: MRTS35 - Recycled Material Blends for Pavements
Location:
Client Sample ID: BS19/366

Other Test Results

Description	Method	Result	Limits
Particle Density - Fine [Q214A]			
Apparent Particle Density (t/m³)		2.62	
Particle Density Dry (t/m³)		2.23	
Particle Density SSD (t/m³)		2.38	
Water Absorption (%)		6.8	
Revision Year 2018			
Date Tested		6/08/2019	
Particle Size Distribution of Soil - Wet Sieving [Q103A]			
Fines Ratio		0.24	
Weak Particles [AS 1141.32]			
Weak Particles (%)		0.4	
Passing 2.36 mm Sieve (%)		31.9	
Date Tested		5/08/2019	
Wet/Dry Strength Variation [Q205ABC]			
Nominal Sample Size (mm)		20	
Nature of Sample		Crushed Rock	
Fraction Size		-13.2 + 9.5 mm	
Wet Strength (kN)		111	
Dry Strength (kN)		161	
Wet/Dry Strength Variation (%)		31	
Revision Year 2018			
Date Tested		30/08/2019	

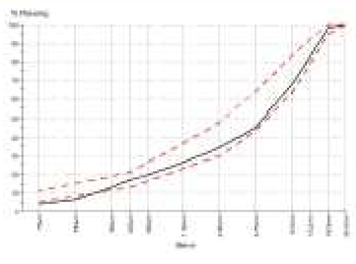
Particle Size Distribution

Method: Q103A

Date Tested: 7/07/2019

Sieve Size	% Passing	Limits
26.5mm	100	100
19.0mm	98	95 – 100
13.2mm	82	78 – 92
9.5mm	67	63 – 83
4.75mm	45	44 – 64
2.36mm	35	30 – 48
1.18mm	26	
600µm	20	
425µm	17	13 – 21
300µm	13	
150µm	6.3	
75µm	4.1	5 – 11

Chart



Comments

Sample tested as received.
Apparent Particle Density performed in accordance with Q109 (2017)
AS 1141.32 - Weak Particles performed in accordance with Q217 (2018)

Form No: 18909, Report No: MAT:BIL19W-0142-S03-1 © 2000-2018 QESTLab by SpectraQEST.com Page 2 of 2

Figure D.6: Supplier B maximum dry density report

Materials Services - Brisbane
Department of Transport and Main Roads
Bulwer Island Laboratory
398 Tingira Street
Pinkenba, Qld, 4008

Telephone: (07) 3066 3345

Queensland Government

Maximum Dry Density Report

Report No: MDD:BIL19W-0142-S03-2
Issue No: 1

Client: ARRB Group
21 McLachlan Street
Fortitude Valley QLD 4006

Project: NACOE P94 - RM001 Material Testing
Location:

Accredited for compliance with ISO/IEC 17025 - Testing

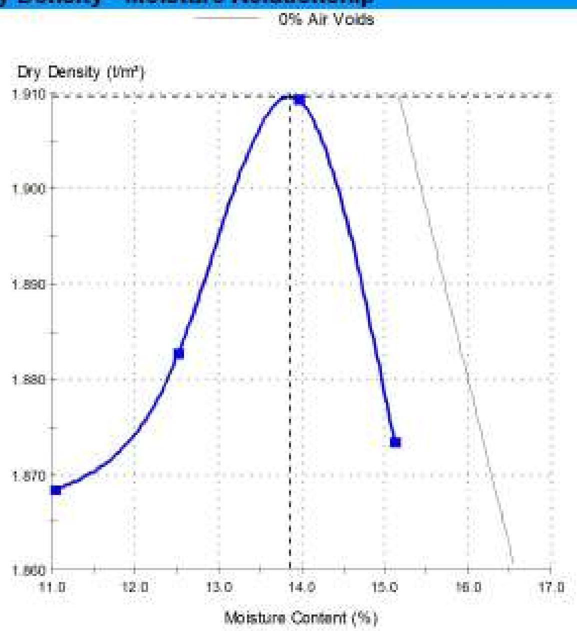
NATA Accredited Laboratory Number 2302

Approved Signatory: Anthony Neary (Senior Materials Technologist)
Date of Issue: 16/08/2019

Sample Details

Location:
Sample ID: BIL19W-0142-S03 **Date Sampled:**
Sampling Method:
Source: **Material:** RM001
Specification: MRTS35 - Recycled Material Blends for Pavements
Location:
Tested By: Jason Maudsley **Date Tested:** 16/07/2019

Dry Density - Moisture Relationship



Test Results

Maximum Dry Density - Standard [Q142A]

Standard MDD (t/m³):	1.91
Standard OMC (%):	14.0
MC Test Method:	Q102A
Oversize Sieve (mm):	
Oversize Material (%):	
Oversize % Basis:	
Curing Duration (h):	3
Plasticity Determination Method:	Q104A

Comments

Sample tested as received. BS19/366
Moisture Content performed in accordance with Q102A (2016)

D.3 SUPPLIER D

Figure D.7: Supplier D materials test report page 1

Queensland Government

Materials Test Report

Materials Services - Brisbane
Department of Transport and Main Roads
Bulwer Island Laboratory
398 Tingira Street
Pinkenba, Qld, 4008

Telephone: (07) 3066 3345

Report No: MAT:BIL19W-0142-S04-1
Issue No: 3
This report replaces all previous issues of report no MAT:BIL19W-0142-S04-1.

Client: ARRB Group
21 McLachlan Street
Fortitude Valley QLD 4006

Project: NACOE P94 - RM001 Material Testing
Location:

Accredited for compliance with ISO/IEC 17025 - Testing

NATA Accredited Laboratory Number 2302

Approved Signatory: Anthony Neary (Senior Materials Technologist)
Date of Issue: 6/09/2019

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Sample Details

Sample ID: BIL19W-0142-S04
Sampling Method:
Date Sampled:
Source:
Material: RM001
Sampled By: Client
Specification: MRTS35 - Recycled Material Blends for Pavements
Location:
Client Sample ID: BS19/367

Particle Size Distribution

Method: Q103A

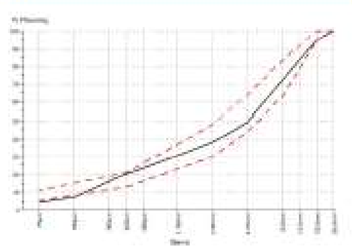
Date Tested: 8/07/2019

Sieve Size	% Passing	Limits
26.5mm	100	100
19.0mm	95	95 – 100
13.2mm	83	78 – 92
9.5mm	72	63 – 83
4.75mm	49	44 – 64
2.36mm	38	30 – 48
1.18mm	31	
600µm	24	
425µm	20	13 – 21
300µm	16	
150µm	6.9	
75µm	4.4	5 – 11

Other Test Results

Description	Method	Result	Limits
Apparent Particle Density of Soil [Q109]			
Apparent Particle Density (t/m³):		2.61	
Atterberg Limits [Q104A/Q105/Q106]			
Linear Shrinkage (%)	Q106		≤3.5
Liquid Limit (%)	Q104A	34.0	≤35
Plastic Limit (%)	Q105	30.0	
Plasticity Index (%)	Q105	4.0	
Weighted Plasticity Index (%)	Q105	79	
Date Tested		4/07/2019	
Degradation Factor - Fine Aggregate [AS 1141.25.3]			
Degradation Factor		15	
Wash water clear?		Yes	
Date Tested		24/07/2019	
Degradation Factor [Q208B]			
Degradation Factor		5	
Date Tested		23/07/2019	
Flakiness Index [Q201]			
Flakiness Index (%)		10	
Date Tested		15/08/2019	
Particle Density - Coarse [Q214B]			
Apparent Particle Density (t/m³)		2.63	
Particle Density Dry (t/m³)		2.27	
Particle Density SSD (t/m³)		2.40	
Water Absorption (%)		6.0	
Revision Year 2018			
Date Tested		24/07/2019	
Particle Density - Fine [Q214A]			
Apparent Particle Density (t/m³)		2.58	
Particle Density Dry (t/m³)		2.12	
Particle Density SSD (t/m³)		2.30	

Chart



Comments

Sample tested as received.
Apparent Particle Density performed in accordance with Q109 (2017)
AS 1141.32 - Weak Particles performed in accordance with Q217 (2018)

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Figure D.8: Supplier D materials test report page 2

Queensland Government

Materials Test Report

Materials Services - Brisbane
Department of Transport and Main Roads
Bulwer Island Laboratory
398 Tingira Street
Pinkenba, Qld, 4008

Telephone: (07) 3066 3345

Report No: MAT:BIL19W-0142-S04-1
Issue No: 3
This report replaces all previous issues of report no MAT:BIL19W-0142-S04-1

Client:	ARRB Group 21 McLachlan Street Fortitude Valley QLD 4006
Project:	NACOE P94 - RM001 Material Testing
Location:	

Accredited for compliance with ISO/IEC 17025 - Testing

NATA Accredited Laboratory Number 2302

Approved Signatory: Anthony Neary (Senior Materials Technologist)
Date of Issue: 6/09/2019

THIS DOCUMENT SHALL NOT BE REPRODUCED EXCEPT IN FULL

Sample Details

Sample ID:	BIL19W-0142-S04
Sampling Method:	
Date Sampled:	
Source:	|
Material:	RM001
Sampled By:	Client
Specification:	MRTS35 - Recycled Material Blends for Pavements
Location:	|
Client Sample ID:	BS19/367

Other Test Results

Description	Method	Result	Limits
Particle Density - Fine [Q214A]			
Water Absorption (%)		8.5	
Revision Year 2018			
Date Tested		6/08/2019	
Particle Size Distribution of Soil - Wet Sieving [Q103A]			
Fines Ratio		0.21	
Weak Particles [AS 1141.32]			
Weak Particles (%)		0.5	
Passing 2.36 mm Sieve (%)		37.0	
Date Tested		5/08/2019	
Wet/Dry Strength Variation [Q205ABC]			
Nominal Sample Size (mm)		20	
Nature of Sample		Crushed Rock	
Fraction Size		-13.2 + 9.5 mm	
Wet Strength (kN)		93	
Dry Strength (kN)		141	
Wet/Dry Strength Variation (%)		34	
Revision Year 2018			
Date Tested		30/08/2019	

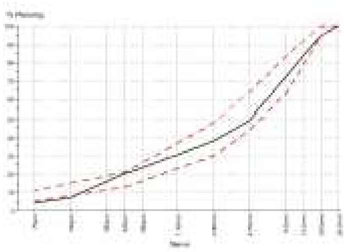
Particle Size Distribution

Method: Q103A

Date Tested: 6/07/2019

Sieve Size	% Passing	Limits
26.5mm	100	100
19.0mm	95	95 – 100
13.2mm	83	78 – 92
9.5mm	72	63 – 83
4.75mm	49	44 – 64
2.36mm	38	30 – 48
1.18mm	31	
600µm	24	
425µm	20	13 – 21
300µm	16	
150µm	6.9	
75µm	4.4	5 – 11

Chart



Comments

Sample tested as received.
Apparent Particle Density performed in accordance with Q109 (2017)
AS 1141.32 - Weak Particles performed in accordance with Q217 (2018)

Form No: 18909, Report No: MAT:BIL19W-0142-S04-1 © 2000-2018 QESTLab by SpectraQEST.com Page 2 of 2

Figure D.9: Supplier D maximum dry density report

Materials Services - Brisbane
Department of Transport and Main Roads
Bulwer Island Laboratory
398 Tingira Street
Pinkenba, Qld, 4008

Telephone: (07) 3066 3345

Queensland Government

Maximum Dry Density Report

Report No: MDD:BIL19W-0142-S04-2
Issue No: 1

Client: ARRB Group
21 McLachlan Street
Fortitude Valley QLD 4006

Project: NACOE P94 - RM001 Material Testing
Location:

Accredited for compliance with ISO/IEC 17025 - Testing

NATA Accredited Laboratory Number 2302
Approved Signatory: Anthony Neary (Senior Materials Technologist)
Date of Issue: 16/08/2019

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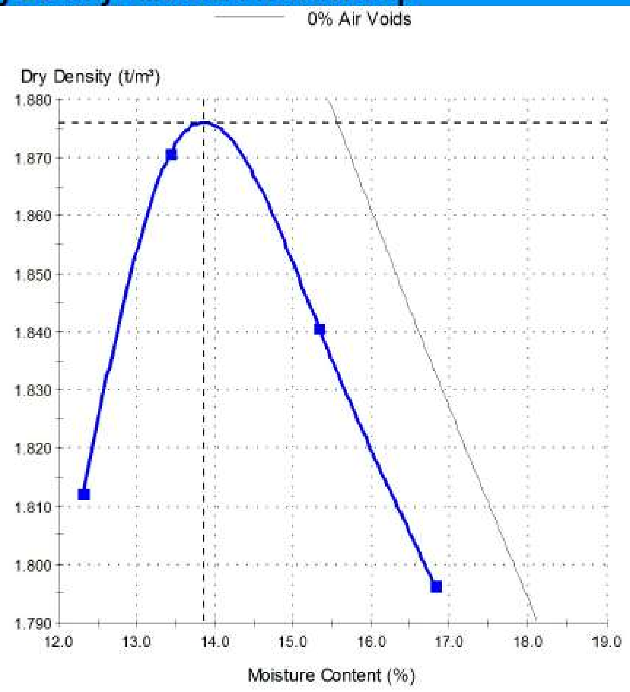
Sample Details

Location:			
Sample ID:	BIL19W-0142-S04	**Date Sampled:**	
Sampling Method:			
Source:		**Material:**	RM001
Specification:	MRTS35 - Recycled Material Blends for Pavements		
Location:			
Tested By:	Jason Maudsley	**Date Tested:**	18/07/2019

Dry Density - Moisture Relationship



Test Results

Maximum Dry Density - Standard [Q142A]

Standard MDD (t/m³):	**1.88**
Standard OMC (%):	**14.0**
MC Test Method:	Q102A
Oversize Sieve (mm):	
Oversize Material (%):	
Oversize % Basis:	
Curing Duration (h):	2
Plasticity Determination Method:	Q104A

Comments

Sample tested as received. BS19/367
Moisture Content performed in accordance with Q102A (2016)

Form No: 18995, Report No: MDD:BIL19W-0142-S04-2 ï¿½ 2000-2018 QESTLab by SpectraQEST.com Page 1 of 1

APPENDIX E WHEEL PRINTS

Figure E.1: Wheel print, 7.96 kN, centred, 0 °C rotation

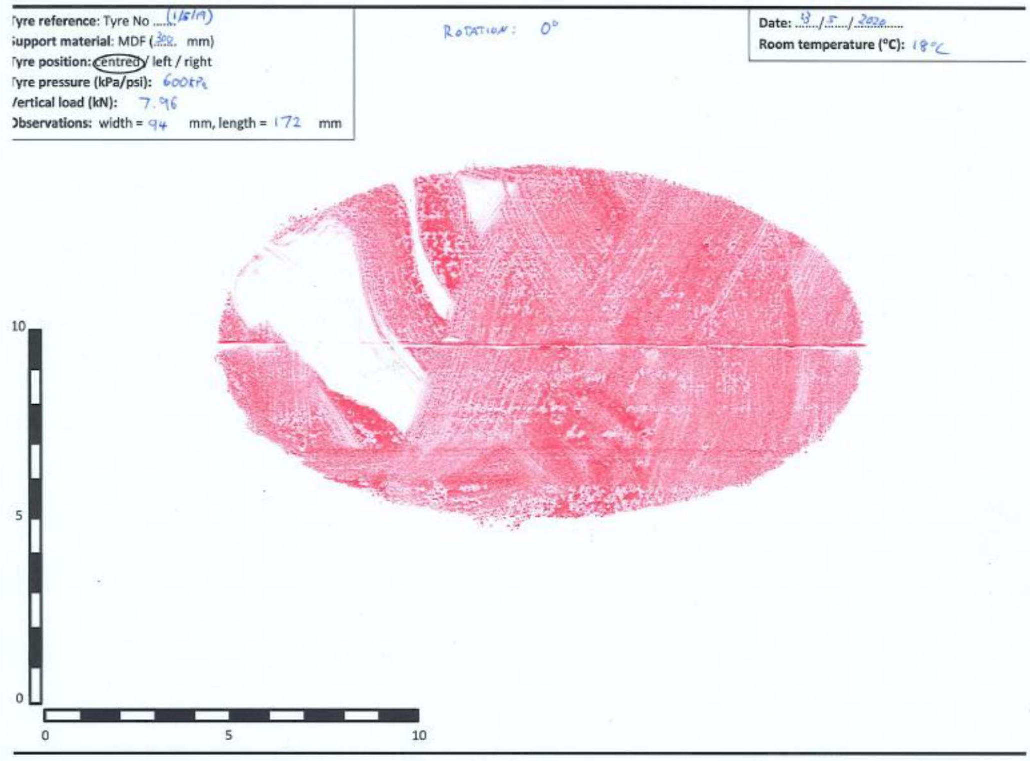


Figure E.2: Wheel print, 7.97 kN, centred, 90 °C rotation

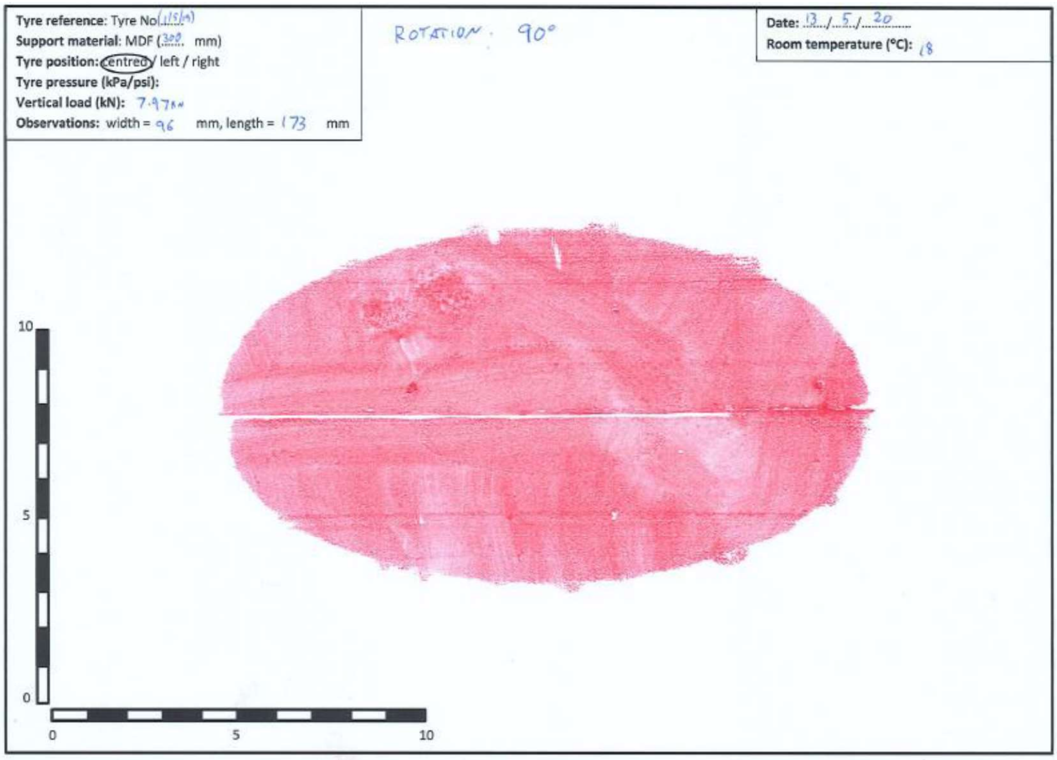


Figure E.3: Wheel print, 8.01 kN, centred, 180 °C rotation

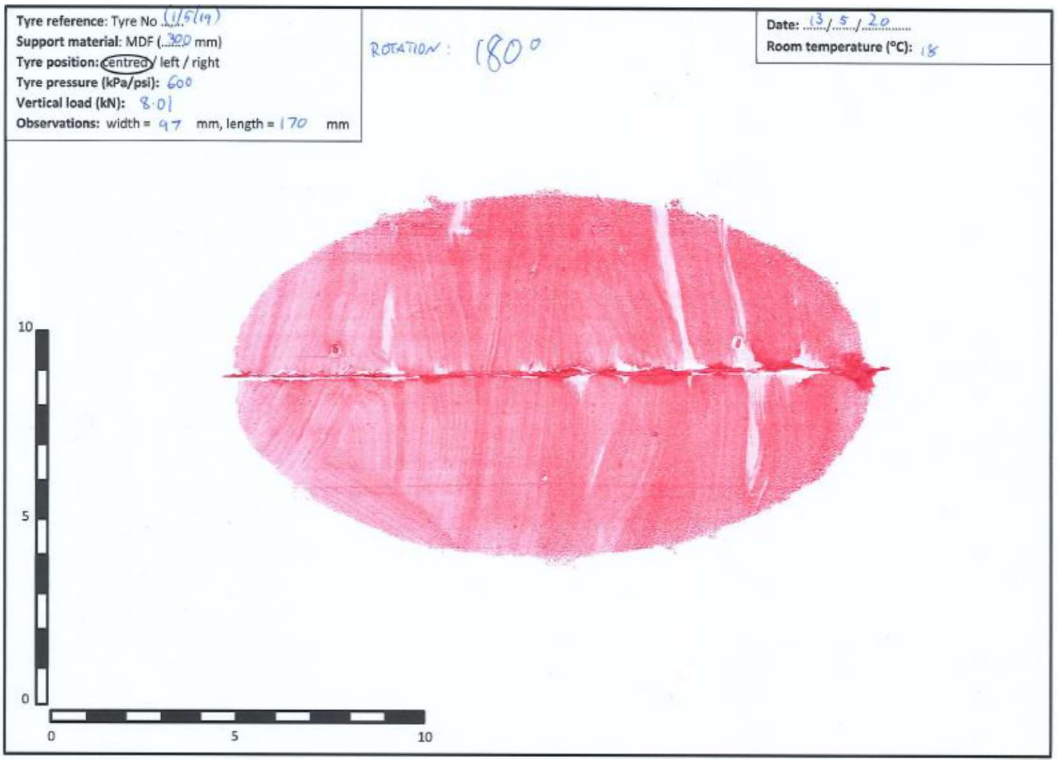
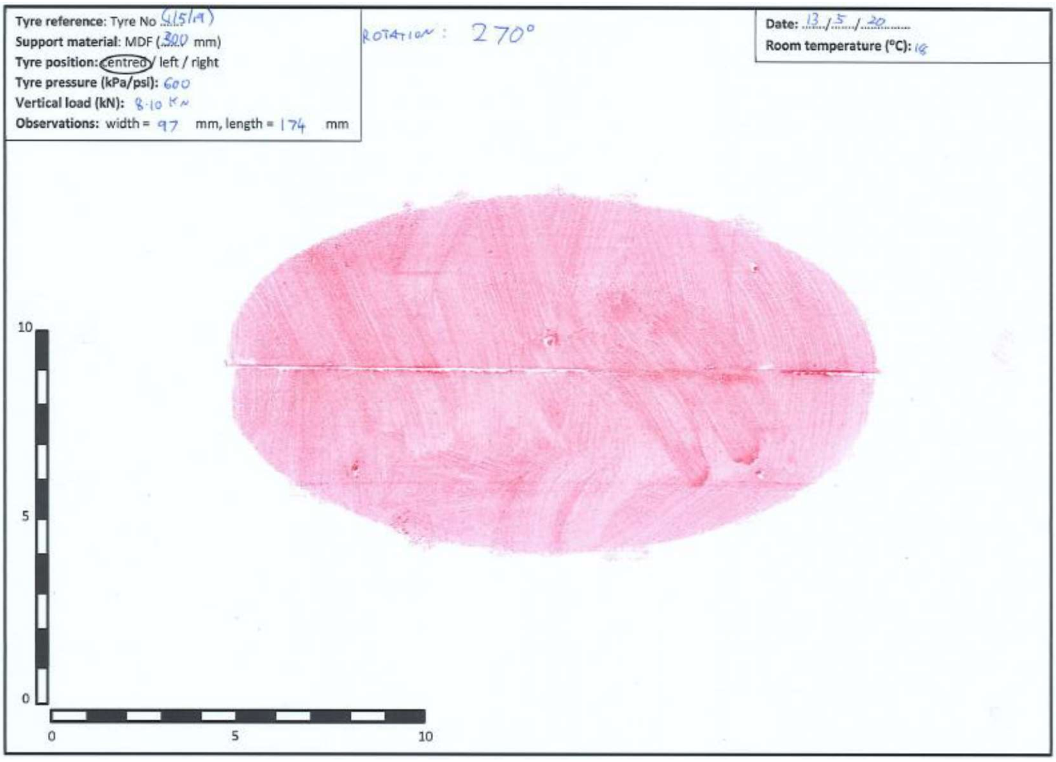


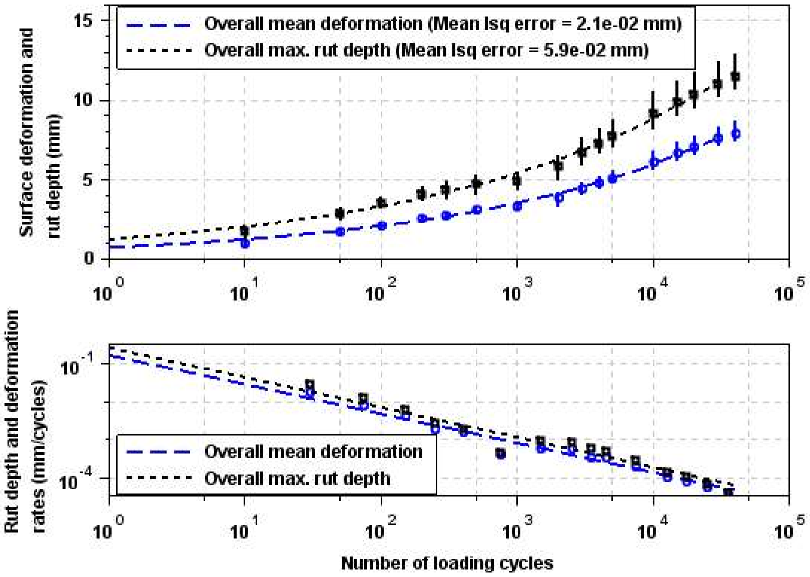
Figure E.4: Wheel print, 8.10 kN, centred, 270 °C rotation



APPENDIX F DEFORMATION AND RUTTING RATE

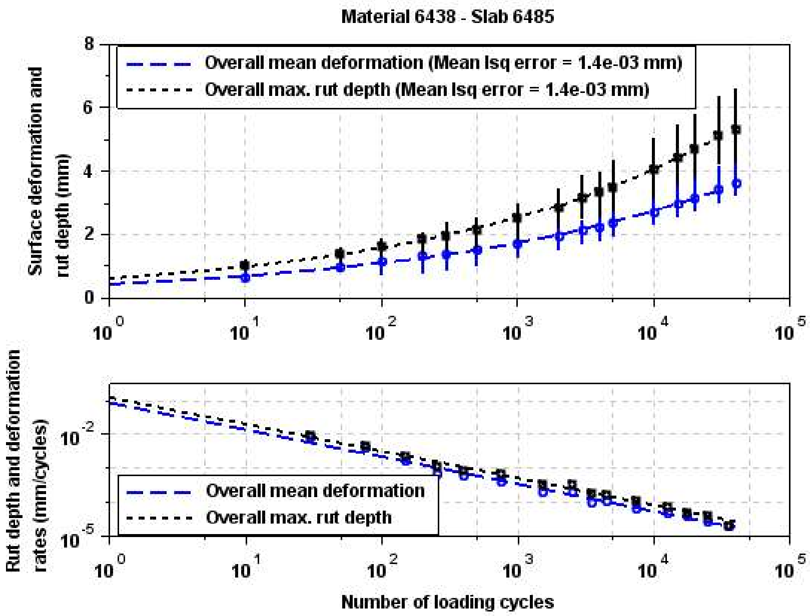
F.1 SUPPLIER B

Figure F.1: Supplier B overall mean deformation and maximum rut depth data and rates



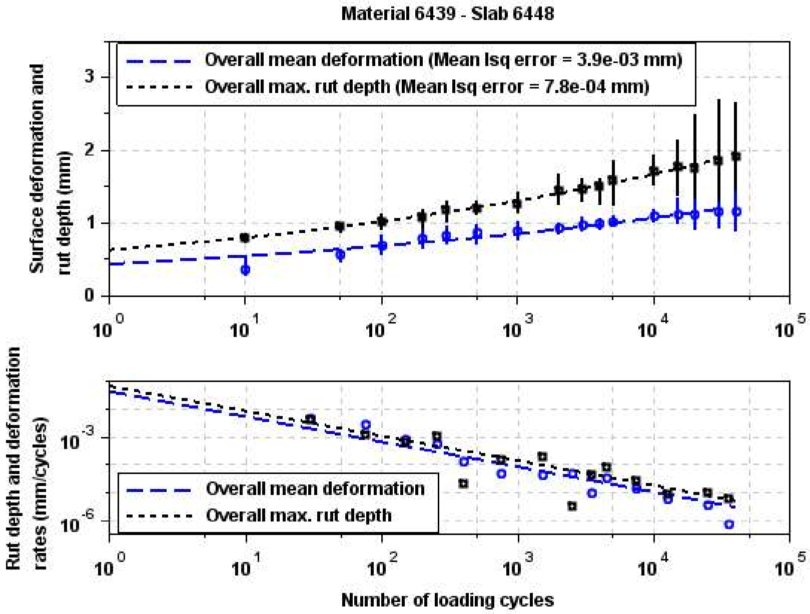
F.2 SUPPLIER C

Figure F.2: Supplier C overall mean deformation and maximum rut depth data and rates



F.3 SUPPLIER D

Figure F.3: Supplier D overall mean deformation and maximum rut depth data and rates



APPENDIX G TEST PHOTOS

G.1 SUPPLIER B

Figure G.1: Surface after compaction

Figure G.2: Sealed surface before wheel tracking

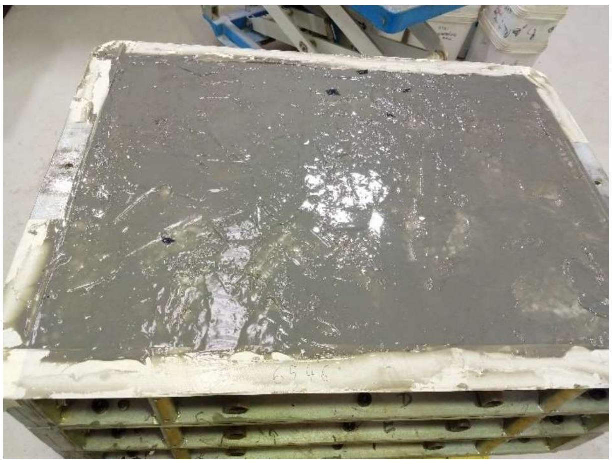


Figure G.3: Sealed surface after wheel tracking

Figure G.4: Rut depth after 40 000 cycles

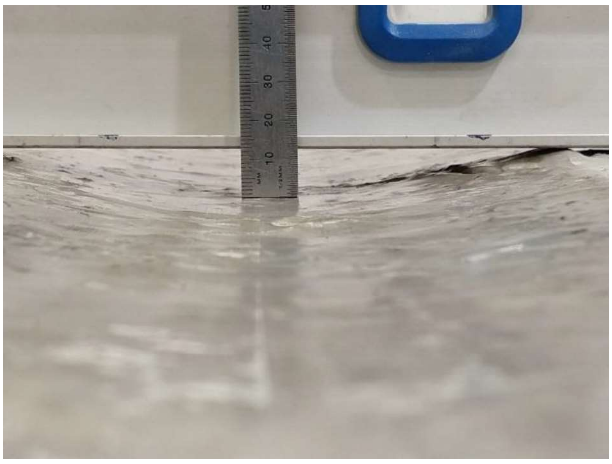


Figure G.5: Preparation for sand replacement

Figure G.6: View from right side when unmoulding

G.2 SUPPLIER C

Figure G.7: Surface after compaction

Figure G.8: Sealed surface before wheel tracking

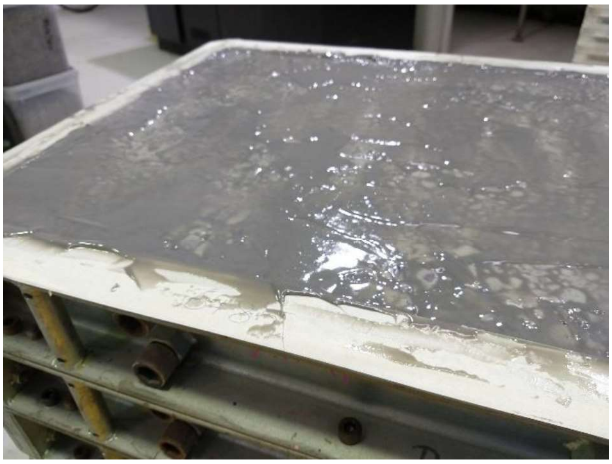


Figure G.9: Sealed surface after wheel tracking

Figure G.10: Rut depth after 40 000 cycles

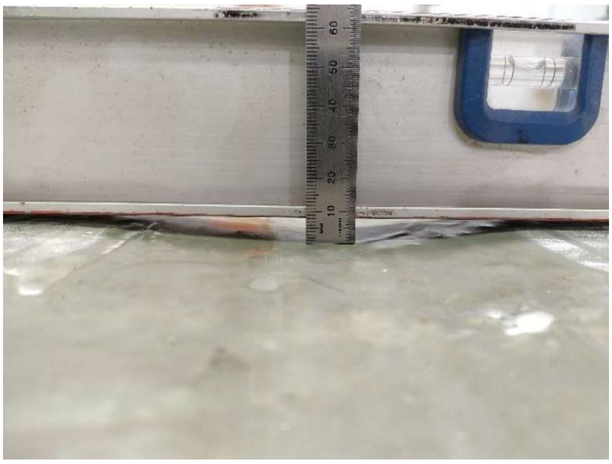


Figure G.11: Preparation for sand replacement

Figure G.12: View from right side when unmoulding

G.3 SUPPLIER D

Figure G.13: Surface after compaction

Figure G.14: Sealed surface before wheel tracking

Figure G.15: Sealed surface after wheel tracking

Figure G.16: Rut depth after 40 000 cycles

Figure G.17: Preparation for sand replacement

Figure G.18: View from right side when unmoulding