Geotechnical characteristics of recycled asphalt

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1 PROJECT BACKGROUND

This project is a collaboration between the Swinburne University of Technology, the Municipal Association of Victoria and Sustainability Victoria.

Asphalt is generally removed from roadways on a regular basis, leading to excess stockpiles of spent asphalt. This material will end up in landfills without a sustainable method to reutilise it. Reclaimed asphalt pavement is the name given to asphalt that has been recycled. Currently 226,000 tonnes of waste asphalt is stockpiled annually in the state of Victoria, Australia (Sustainability-Victoria 2010).

Traditional footpath and bicycle path building materials are becoming scarce in some regions. In some cases, the use of these materials is unsustainable from both an environmental and cost perspective. This has led to this proposed project to investigate the usage of recycled asphalt in these applications. The development of a procedure for the evaluation of reclaimed asphalt in footpaths and bicycle paths as a base, and sub-base material would result in an increased level of confidence within local government councils as to their likely in-service performance and appropriate application.

This applied research project is significant as it will assess the geotechnical engineering properties and performance of recycled asphalt materials and assess its performance in footpaths and shared paths, reduce the demand for virgin materials and reduce the quantity of material deposited in landfill. This project will investigate the usage of reclaimed asphalt in blends with crushed rock and crushed concrete in footpath base and subbase applications. Geotechnical laboratory testing for this project was carried out at Swinburne.

The project outcomes include:

- Assist local government councils in the development of an accepted process for the evaluation of reclaimed asphalt pavements.
- Provide improved knowledge in order to support the development and lead to improvements to the material specifications, construction standards and the geotechnical design of footpaths and bicycle paths based on the research results.
- Develop long-term strategic research alliances between academic institutions (SUT) and local Victorian government councils in order to apply advanced knowledge and technologies to the usage of reclaimed Construction and Demolition materials.

2 RECYCLED MATERIAL SOURCES

Samples of recycled asphalt, crushed concrete and crushed rock (manufactured from recycled basalt excavation rock) for this project was obtained from Alex Fraser Recycling site at Laverton North.

3 LABORATORY TESTING METHODOLOGY

This section describes the test methods that were used to determine the engineering properties of recycled asphalt when blended with various proportions of crushed concrete (Class 3) and crushed rock (Class 3). The laboratory testing program comprised of the following tests:

- Particle Size Distribution
- Particle Density
- Water Absorption
- Modified Compaction
- Modified California Bearing Ratio (CBR)
- pH
- Clay Content
- Plasticity Index
- Organic Content
- Los Angeles Abrasion Loss
- Flakiness Index
- Permeability
- Resilient modulus tests (for 15% RAP with crushed concrete and crushed rock).

Particle Size Distribution

Particle size distribution tests were performed in accordance with AS 1141.11 "Particle size distribution by sieving" (AS 1141.11, 1996). The Australian Standard sieves with the aperture sizes of 19 mm, 13.2 mm, 9.5 mm, 4.75 mm, 2.36 mm, and 75 μm will be used. The minimum amount of 3 kilograms will be sieved and the particle size distribution will be plotted for each blend.

Particle Density

Particle density tests for coarse material retained on 4.75 mm sieve were performed in accordance with AS 1141.6.1 "Particle density and water absorption of coarse aggregate–Weighing-in-Water Method". Particle density tests for fine material passing 4.75 mm sieve will be undertaken in accordance with AS 1141.5 "Particle density and water absorption of fine aggregate".

Water Absorption

Water absorption tests for coarse aggregates were undertaken in accordance with AS 1141.6.1 "Particle density and water absorption of coarse aggregate–Weighing-in-Water Method". Water absorption tests for fine aggregates were performed in accordance with AS 1141.5 "Particle density and water absorption of fine aggregate".

Modified Compaction

Modified compaction tests were undertaken in accordance with AS 1289.5.2.1 "Soil compaction and density tests – Determination of the dry density/moisture content relation of a soil using modified compactive effort" to determine the maximum dry density and optimum moisture content. Samples will be prepared in a 105 mm diameter mould, having a capacity of 1000 cm^3 from coarse and fine aggregates smaller than 19 mm (i.e. passing the 19 mm sieve).

Modified California Bearing Ratio (CBR)

California Bearing Ratio tests were undertaken in accordance with AS 1289.6.1.1 "Soil strength and consolidation tests – Determination of the California Bearing Ratio of a soil – Standard laboratory method for a remoulded specimen". The samples will be prepared at their optimum moisture content using modified compactive effort (98% to 100% Maximum Dry Density) and tested under four days soaked condition. As each prepared sample will be 19 mm minus, there will be no need to remove any oversize and the full sample can be tested.

pH

pH tests were performed in accordance with AS 1289.4.3.1 "Soil chemical tests - Determination of the pH value of a soil - Electrometric method". All samples will consist of material passing 2.36 mm sieve.

Clay Content

Hydrometer tests were undertaken to determine the clay content of samples in accordance with ASTM D 422-63 “Standard Test Method for Particle-Size Analysis of Soils”.

Plasticity Index

Plastic limit, liquid limit and plasticity index tests were undertaken in accordance with AS 1289.3.1.1 “Soil classification tests – Determination of the liquid limit of a soil – Four point Casagrande method” for liquid limit and AS 1289.3.2.1 “Soil classification tests – Determination of the plastic limit of a soil – Standard method” for plastic limit.

Organic Content

Organic content tests were undertaken in accordance with ASTM D 2974-00 “Standard Test Methods for Moisture, Ash and Organic Matter of Peat and Other Organic Soils”.

Los Angeles Abrasion Loss

Los Angeles Abrasion Loss tests were undertaken in accordance with AS 1141.23 “Methods for sampling and testing aggregates – Los Angeles Value”.

Permeability

Permeability tests were undertaken in accordance with AS 1289.6.7.2 “Soil strength and consolidation tests – Determination of permeability of a soil – Falling head method for a remoulded specimen”.

Repeated Load Triaxial Tests

The RLT test provides resilient modulus – permanent deformation parameters that uniquely describe the material response to traffic loading under prevailing physical conditions. These parameters are used as input to the design and analysis of pavement structures. The test results can also be used to establish a material selection criterion based on its ability to perform effectively in terms of permanent deformation sustained. In this investigation, the RLT test was performed according to Austroads Repeated Load Triaxial Test Method AG: PT/T053 (2000). The repeat load triaxial testing consists of two phases of testing, permanent strain testing (Phase 1) followed by resilient modulus testing (Phase 2) on the same sample.

4 TESTING OF RECYCLED ASPHALT (RAP) BLENDS

Reclaimed Asphalt Pavement (RAP) was tested in this research (100 RAP) as well as in 15% RAP blends with crushed concrete (15RAP/85CC) and crushed rock (15RAP/85CR) for the various tests. The blend mixtures were prepared by hand mixing to the required percentages by weight. The details of the RAP blended with crushed concrete and crushed rock for each of the tests are presented in Tables 1.

Table 1: RAP Blends

Sample description	Blending percentage		
	Crushed Concrete (CC) Class 3	Crushed Rock (CR) Class 3	RAP
100 RAP			100
15 RAP/85 CC	85		15
15 RAP/85 CR		85	15

The particle size distribution results prior to compaction and after compaction for RAP blended with crushed concrete (Class 3) and crushed rock (Class 3) is summarised in Table 2 and Table 3. The RAP blends meets the grading requirements of the current MAV specification (MAV, 2010) for usage in footpaths and shared paths.

Table 2: Particle size distribution (before compaction)

Sample Description	100RAP	15RAP/85CC	15RAP/85CR
RAP Content (%) by weight	100	15	15
Particle size (mm)	Percentage of total passing (%)		
19.0	100	98.2	96.5
13.2	92.7	88.2	82.9
9.5	84.4	79.3	69.3
4.75	56.5	59.2	48.4
2.36	38.2	38.2	35.5
0.075	3.4	0.2	0.2

Table 3: Particle size distribution (after compaction)

Sample Description	RAP100	CC85/RAP15	CR85/RAP15
RAP Content (%) by weight	100	15	15
Particle size (mm)	Percentage of total passing (%)		
	Ser 1	Ser 1	Ser 1
19.0	100	100	97.9
13.2	92.7	80.6	91.4
9.5	84.4	73.6	78.9
4.75	56.5	50.3	50.5
2.36	38.2	35.9	30.6
0.075	3.4	4.1	1.9

Table 4 summarises the engineering properties of RAP as well as its properties when blended with crushed concrete (Class 3) and crushed rock (Class 3).

Table 4: Engineering properties of RAP blended with crushed concrete (Class 3) and crushed rock (Class 3).

Sample Description		**100RAP**	**15RAP/ 85CC**	**15RAP/ 85CR**
Recycled Asphalt (RAP) by weight (%)		**100**	**15**	**15**
D_{10} (mm)		0.46	0.36	0.57
D_{30} (mm)		1.9	1.7	1.8
D_{50} (mm)		4	5.1	3.5
D_{60} (mm)		5.3	7.5	4.9
C_u		11.5	20.8	8.6
C_c		1.48	1.07	1.16
Gravel content (%)		45.5	50	40
Sand content (%)		54.5	50	60
Fines content (%)		3.4	0	0
USCS classification		GW	GW	GW
Particle density – Coarse (kN/m^3)		2.4	2.9	2.6
Particle density – Fine (kN/m^3)		2.4	2.5	2.8
Water absorption – Coarse (%)		8.6	8.4	10.2
Water absorption – Fine (%)		22.4	18.6	11.5
Organic content (%)		5.10	2.55	0.88
pH		7.6	11.8	7.6
Fine content (%)		3.4	6.5	10.7
Flakiness index		22	35	33
Hydraulic conductivity (m/s)		3.5×10^{-7}	5.8×10^{-7}	1.0×10^{-6}
Los Angeles abrasion loss		42	39	34
California Bearing Ratio (%)		30-35	66	91
Compaction (Modified)	Max dry density (kN/m^3)	19.62	19.52	21.38
	Opt. moisture content (%)	8.1	11.5	9.0

4.1.1 Particle Size Distribution

The grading limits of all blends before compaction were found to be within the specified (MAV, 2010) limits. The grading limits of the blends are presented in Figure 1.

The before and after compaction gradings of the random samples indicate that the materials appear to be remaining reasonably well graded through the compaction process and this will generally aid the compaction process. The after compaction gradings show that some breakdown is occurring under compaction; however compliance with normal after compaction requirements is still achieved. It would be interesting to see what level breakdown occurs under a field compaction conditions and field trials are suggested to gauge the potential impacts. The difference in the trends of the curves would be due to slight variations in the constitution of the samples.

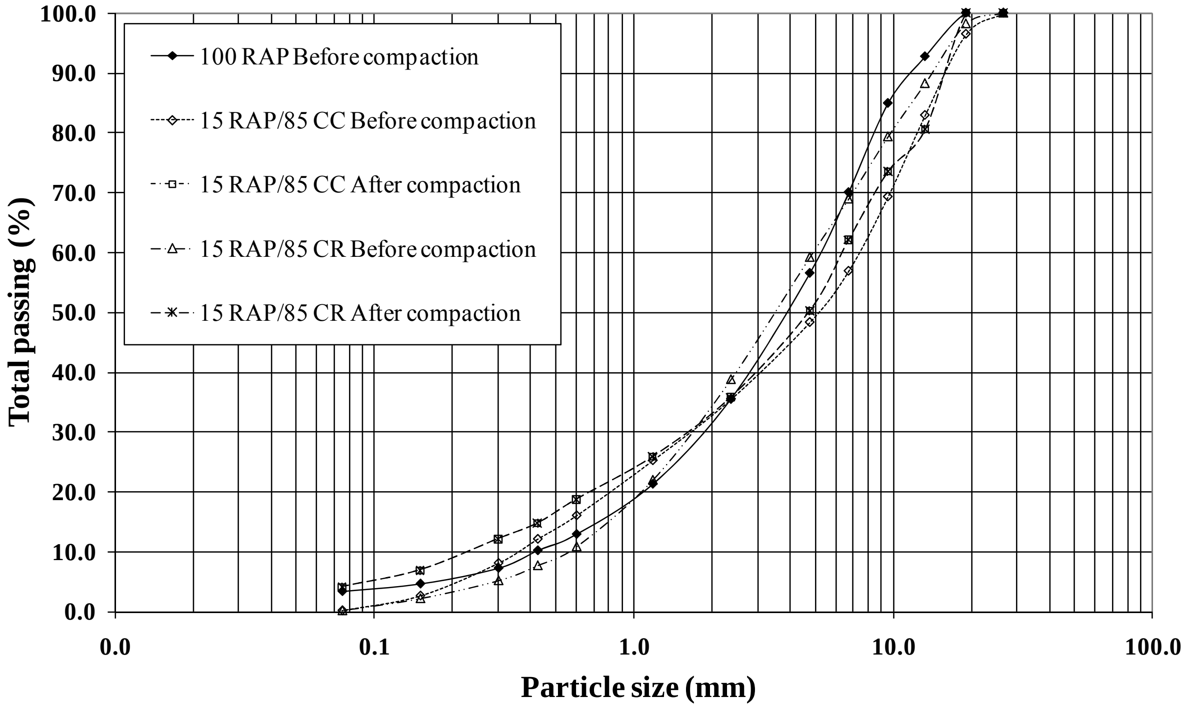

Figure 1: Particle size distribution (before and after compaction) for RAP blended with crushed concrete (Class 3) and crushed rock (class 3)

4.1.2 Particle Density

❖ **Coarse material**

The particle densities of coarse blended aggregates passing 19 mm and retained on 4.75 mm are in the range between 2.4 to 2.9. The results are within reasonable range.

❖ **Fine material**

The particle densities of fine blended aggregates passing 4.75 mm range between 2.4 to 2.8.

4.1.3 Water Absorption

❖ **Coarse material**

The water absorptions of coarse blended aggregates passing 19 mm and retained on 4.75 mm range between 8.4% and 10.2%.

❖ **Fine material**

The water absorptions of fine blended aggregates passing 4.75 mm range between 11.5% and 22.4%.

4.1.4 Modified Compaction

The maximum dry densities of blends following compaction range between 19.52 kN/m^3 and 21.38 kN/m^3 as presented in Table 4. The optimum moisture contents for blends range between 8.1% and 11.5%.

4.1.5 California Bearing Ratio (CBR)

The CBR value of RAP blended with crushed rock was 91% while RAP blended with crushed concrete was 66. This exceeds the minimum value of 40% specified in the MAV specifications for footpaths.

The CBR of 100RAP was between 30-35%. This is less than the minimum value of 40% specified in the MAV specifications for footpaths (MAV, 2010).

4.1.6 pH

The pH values of all blends range between 7.6 and 11.8. This indicates that the blends are alkaline by nature.

4.1.7 Fine Content

The fine contents in all blends were less than 10%.

4.1.8 Plasticity Index

As the clay content in all the blends was low, the plastic limit and liquid limit could not be obtained. This is because the Atterberg limit is directly related to clay mineralogy and as such, higher clay contents result in higher plasticity.

4.1.9 Organic Content

The organic contents of blends range between 0.88% and 5.10%.

4.1.10 Los Angeles Abrasion loss

The Los Angeles Abrasion loss values of blends were between 34 and 42. This is within the maximum value of 60% specified in the MAV specifications for footpaths (MAV, 2010).

4.1.11 Permeability

The coefficient of permeability results of the blends is 10^{-6} to 10^{-7} m/s.

4.1.12 Repeated Load Triaxial Tests

Table 5 presents the Repeated Load Triaxial (RLT) test results based on the 15% RAP blends as compared to typical quarry aggregates. Fig 2 to 4 presents the RLT test results for the 15RAP/85CC blends while Fig 5 to 7 presents the RLT test results for the 15RAP/85CR blends.

From the RLT experimental study and the results in Table 5, it can be concluded that RAP blends would perform satisfactorily around target moisture contents of 59 to 78% of the OMC for the 15RAP/85CC blends and at 62% of the OMC for the 15RAP/85CR blends. At higher moisture levels than these, the strength of these materials will be reduced and would lead to failure.

Table 5: Range of permanent strain and resilient modulus from permanent strain testing (Phase 1) for RAP blends at the end of each loading

Material	**Permanent Strain Testing**	Target Moisture Content (% of the OMC)	Actual Moisture Content (% of the OMC)	**Stage1: confining stress = 50 kPa deviator stress = 150 kPa**	**Stage2: confining stress = 50 kPa deviator stress = 250 kPa**	**Stage3: confining stress = 50 kPa deviator stress = 350 kPa**
15RAP/ 85CC	Permanent strain (micro strain)	90	88	8866	Failed	Failed
		75	78	1972	2768	3298
		60	59	878	1392	1823
	Resilient modulus (MPa)	90	88	232	Failed	Failed
		75	78	412	611	728
		60	59	587	774	928
15RAP/ 85CR	Permanent strain (micro strain)	75	73	Failed	Failed	Failed
		60	62	3180	5368	8049
	Resilient modulus (MPa)	75	73	Failed	Failed	Failed
		60	62	285	372	430
Typical Quarry Material	Permanent strain (micro strain)	90	90	7000-15000	10000-20000	10000->20000
		80	80	5000-10000	7000-15000	10000->20000
		70	70	3000-10000	4000-15000	5000-20000
	Resilient modulus (MPa)	90	90	125-300	150-300	175-300
		80	80	150-300	175-300	200-300
		70	70	175-350	200-400	225-400

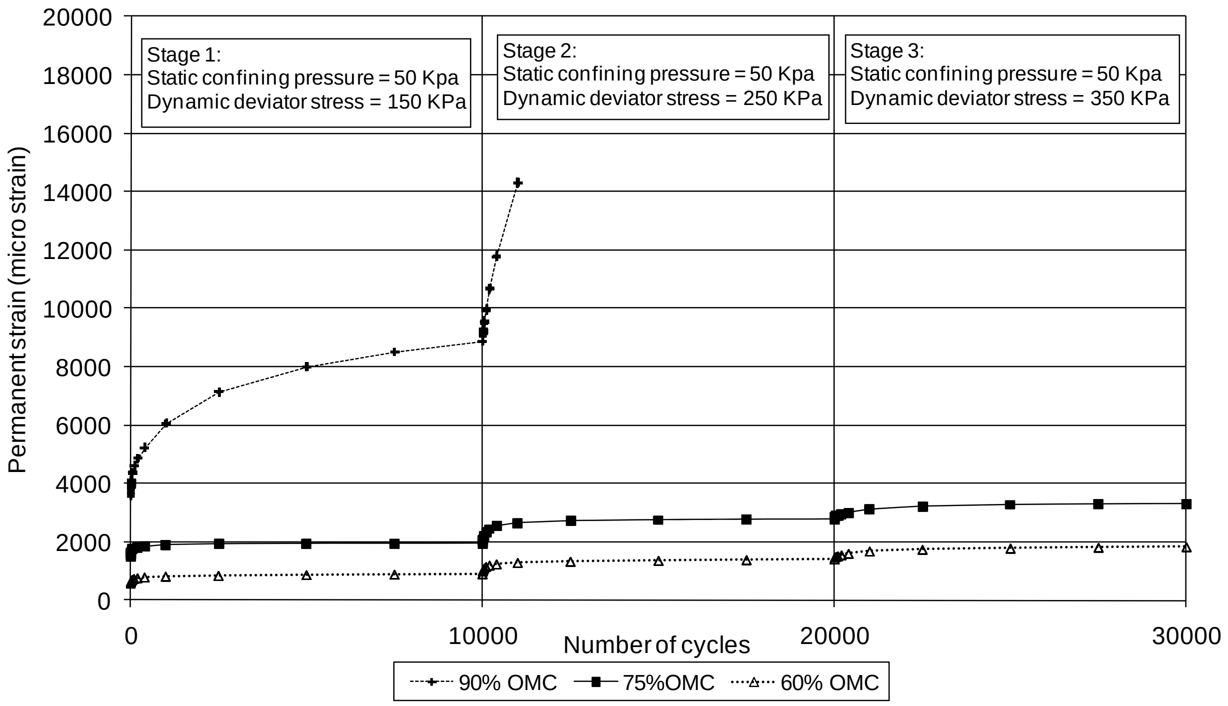

Figure 2: 15RAP/85CC permanent strain test: Permanent strain versus number of cycles.

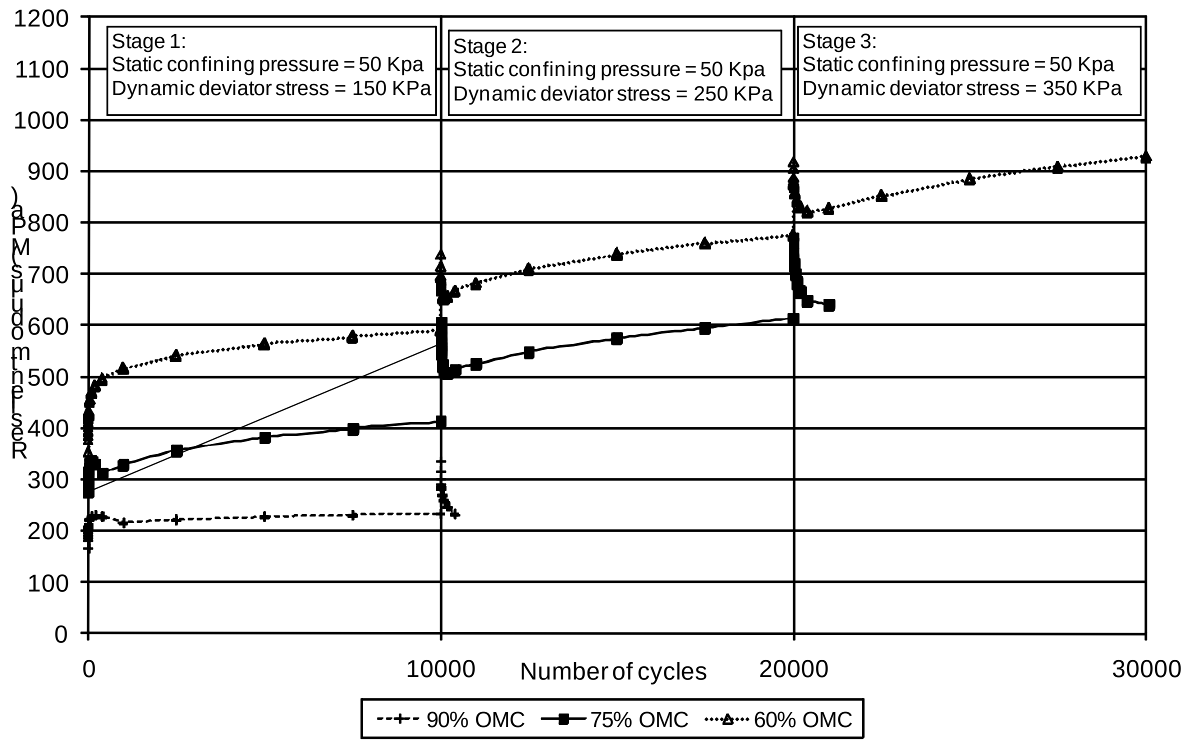

Figure 3: 15RAP/85CC permanent strain test: resilient modulus testing results

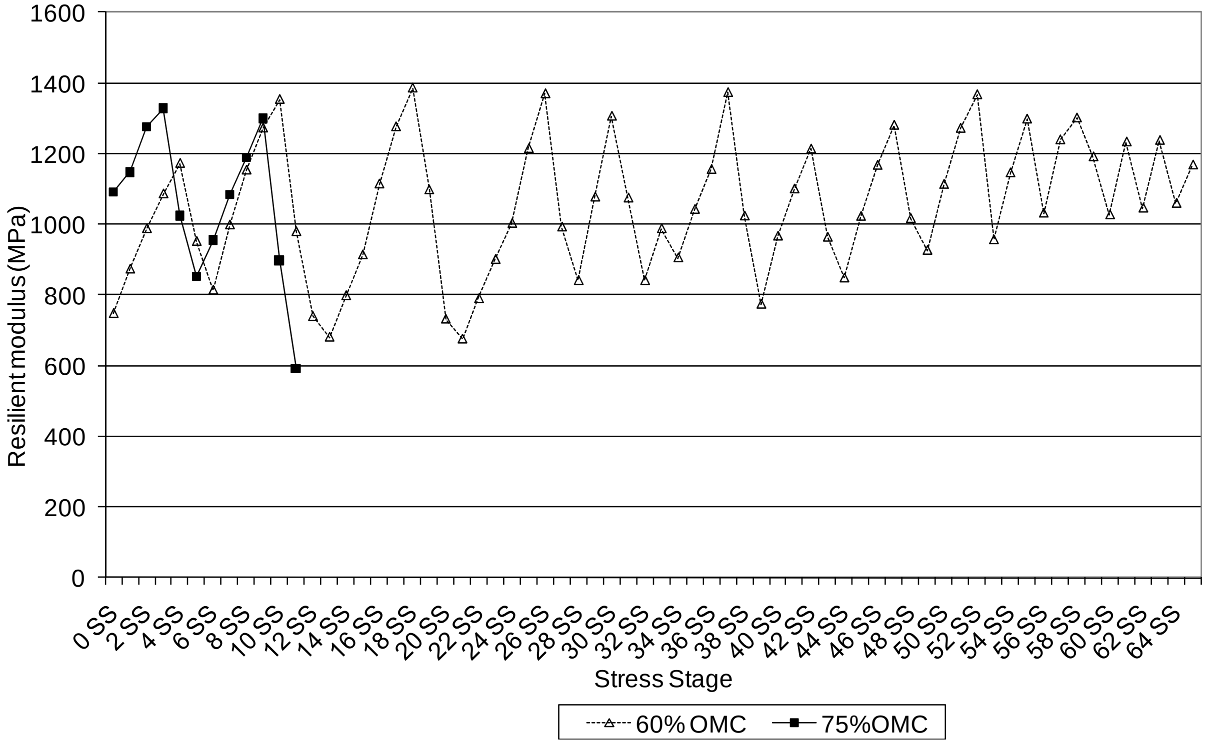

Figure 4: 15RAP/85CC resilient modulus test: resilient modulus testing results

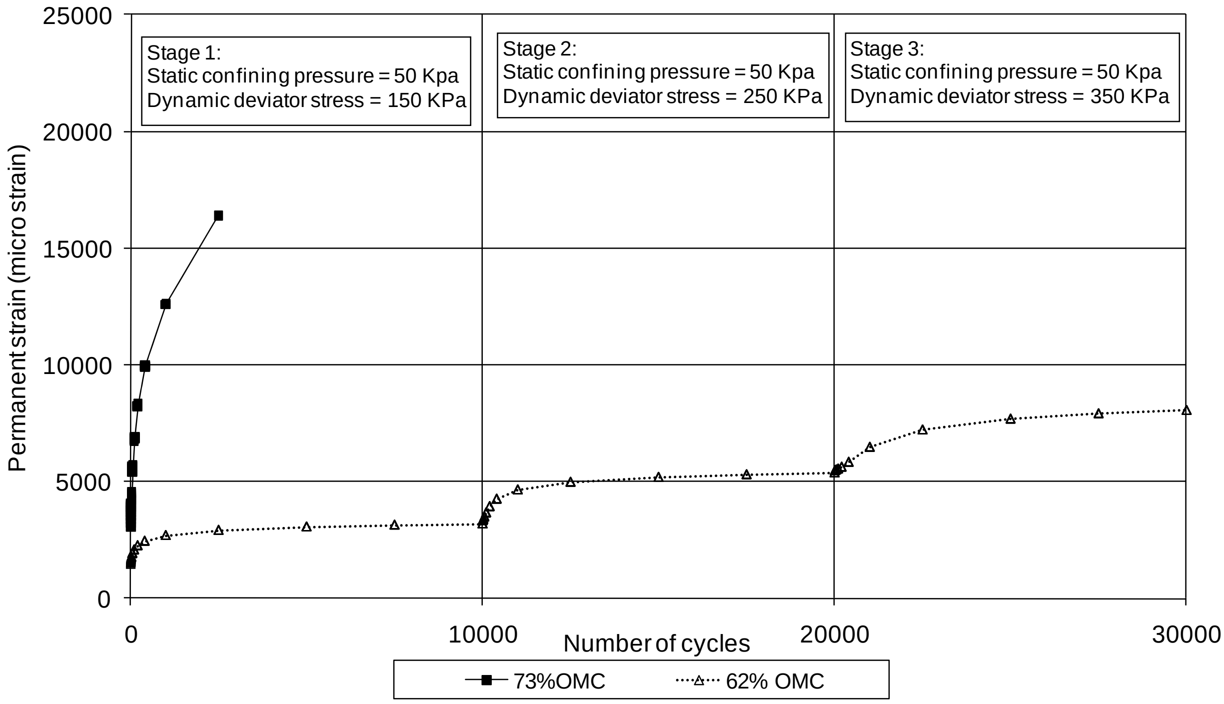

Figure 5: 15RAP/85CR permanent strain test: Permanent strain versus number of cycles.

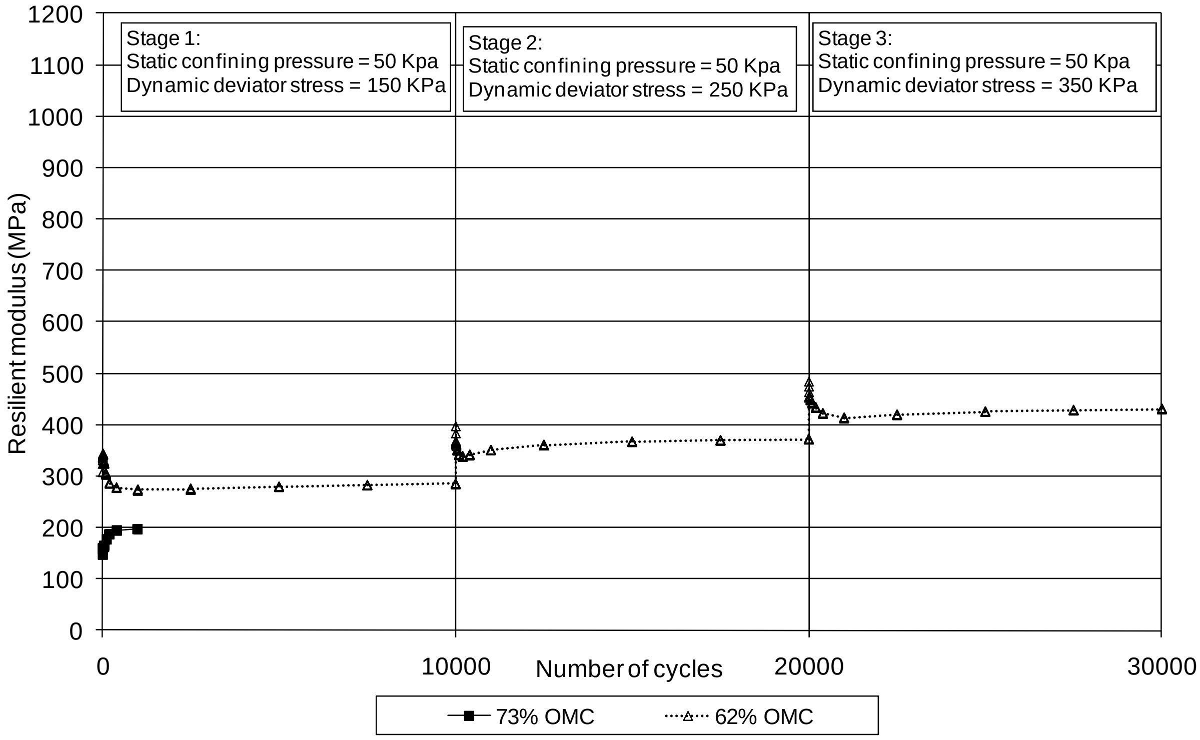

Figure 6: 15RAP/85CR permanent strain test: resilient modulus testing results

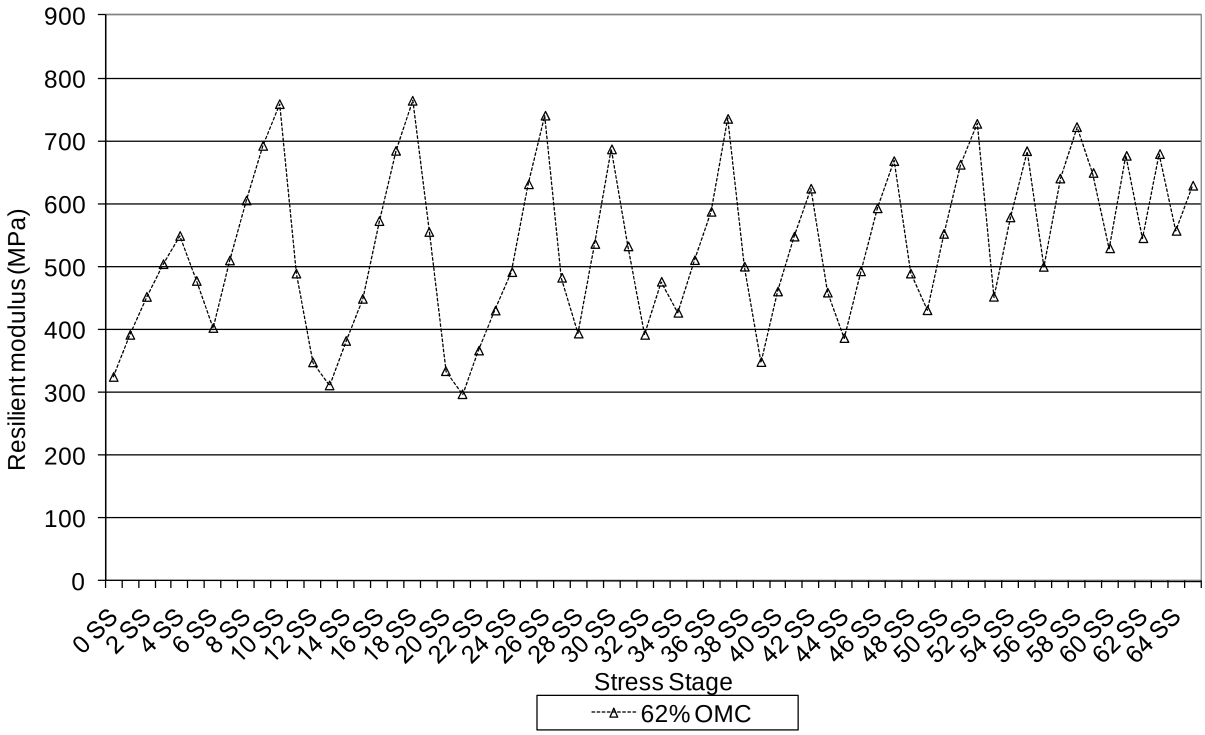

Figure 7: 15RAP/85CR resilient modulus test: resilient modulus testing results

5 COMPARISON WITH SPECIFICATIONS FOR FOOTPATH AND SHARED PATHS

Current specifications issued by the Municipal Authority of Victoria (MAV, 2010) for reclaimed demolition materials in footpaths and shared paths presently specify a minimum CBR value of 40%, maximum flakiness index value of 35% and maximum LA abrasion value of 60%.

Based on these current specifications requirements, the following can be concluded based on the experimental testing results:

- 15RAP/85CR meets the necessary requirements for usage in footpaths and shared paths.
- 15RAP/85CC meets the necessary requirements for usage in footpaths and shared paths.
- 100RAP has a CBR of 30 to 35% (compared to 40% requirement) which is below the specified minimum CBR requirements for usage in footpaths.

6 CONCLUSION

The results of the laboratory testing undertaken in this research has shown overall that the incorporation of 15% RAP into basaltic crushed rock or crushed concrete has “low to minimal affect” on the physical and mechanical properties of the original material when used in footpath applications.

The 15% RAP blends with crushed concrete and crushed rock tested were within the specified requirements for footpaths and shared paths. The laboratory results indicates that initially up to 15% RAP could be considered with crushed concrete and crushed rock blends for footpath and shared path applications. Further proportions may be considered subject to additional laboratory and field testing.

As RAP properties may vary significantly depending on the source of the RAP and the supplier, it is recommended that the necessary quality control tests be undertaken to ensure the RAP blends supplied to a project site meet all the specified requirements as outlined in this report and the MAV specifications.

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