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RECLAIMED ASPHALT PAVEMENT/RECYCLED CONCRETE AGGREGATE BLENDS IN PAVEMENT SUBBASES: LABORATORY AND FIELD EVALUATION

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Abstract

In recent years, efforts have been made to incorporate Reclaimed Asphalt Pavement (RAP) into pavement base or subbase applications by means of cement binder stabilization. This approach however may not be an environmentally friendly solution, due to the high carbon footprint involved in the production of Portland cement. Recycled Concrete Aggregate (RCA), on the other hand has been widely accepted in pavement applications. The sustainable solution of blending RAP with RCA was investigated in this research in an attempt to facilitate the usage of this blend as an alternative pavement subbase material. An extensive suite of geotechnical laboratory tests were undertaken on RAP with contents of 100%, 50%, 30% and 15% in blends with RCA. Results of the research study indicated that RAP/RCA blends when used with a low 15% RAP content meet the Repeated Load Triaxial requirements for use in pavement subbase layers. Results of field performance of a pavement subbase constructed with untreated 100% RAP at a private haul road field demonstration site confirmed that untreated 100% RAP had insufficient strength requirements to meet local road authority pavement subbase requirements. RAP and RAP/RCA blends, though found in this study to be not fully compliant with the local road authorities requirements for pavement subbases, could be potentially considered for lower traffic usage such as haul roads and footpaths.

Keywords: Reclaimed asphalt pavement; recycled concrete aggregate; pavement; subbase; geotechnical.

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Introduction

Construction and demolition solid waste stockpiles are growing globally due to the rapid increase in construction and rehabilitation activities in the infrastructure sector. In recent years, there has been a growing interest in the usage of various recycled Construction and Demolition (C&D) waste materials in road and pavement applications such as base and subbase layers due to the high cost and diminishing sources of high quality naturally occurring aggregates (Landris, 2007, Disfani et al., 2011, Hoyos et al., 2011, Arulrajah et al., 2013b). C&D wastes that have been recently assessed to be viable materials for roads, pavements, footpaths and other civil engineering applications include reclaimed asphalt (Taha et al., 2002, Hoyos et al., 2011, Puppala et al., 2011), recycled concrete (Poon and Chan, 2006, Azam and Cameron, 2012, Gabr and Cameron, 2012), recycled brick (Aatheesan et al., 2010, Arulrajah et al., 2012a) and recycled glass (Wartman et al., 2004, Landris, 2007, Ali et al., 2011, Disfani et al., 2012, Imteaz et al., 2012, Arulrajah et al., 2013a).

The rehabilitation of pavements generates huge amounts of Reclaimed Asphalt Pavement (RAP) (Allan and Timothy, 1999, Daniel and Lachance, 2005). Similarly, the construction sectors generate large amount of Recycled Concrete Aggregate (RCA) from the demolition of buildings and rehabilitation of concrete pavements (Oglesby et al., 1989, Apotheker, 1990, Wood, 1992, Gavilan and Bernold, 1994). RAP and RCA can be reused as there is an increasing demand for the use of alternative materials in pavements due to high costs of landfills, associated energy costs and increasing costs of diminishing naturally occurring aggregates.

Currently RAP is predominantly reused in hot mix asphalt production as an aggregate (Huang et al., 2005, Carter and Stroup-Gardiner, 2007). In recent years, efforts have been made to incorporate RAP into pavement base or subbase applications (e.g. Maher and Jr., 1997, Taha et al., 2002, Park, 2003, Taha, 2003, Blankenagel and Guthrie, 2006, Poon and Chan, 2006, Cho et al., 2011, Hoyos et al., 2011, Puppala et al., 2011, Piratheepan et al., 2013). RAP stabilized with cement binders has been reported to perform satisfactorily in pavement base and subbase layers (Hoyos et al., 2011, Puppala et al., 2011). Due to the high carbon footprint involved in the production of Portland cement, RAP stabilization using cement binders is however not considered an environmentally friendly solution.

RCA in recent years is widely being accepted for use in pavement base and subbase applications (Poon and Chan, 2006, Arulrajah et al., 2012b, Azam and Cameron, 2012, Gabr and Cameron, 2012). The application of RAP and RCA in pavement subbase as an aggregate has however to date been limited due to the lack of reported laboratory testing and field testing results. Application of RAP in pavements base and subbase has limitations as it shows high water absorption and Los Angeles abrasion and low California Bearing Ratio (CBR) values (Taha et al., 1999), which do not satisfy many local road authority specification. On the other hand, RCA shows comparatively low water absorption and Los Angeles abrasion and high CBR values and satisfies the requirements to be used in pavement subbase layers (Arulrajah et al., 2013b).

An environmentally friendly option was investigated in this research by blending RAP with RCA to investigate the feasibility of using this blend as an alternative pavement

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subbase material. An extensive suite of geotechnical laboratory tests were undertaken on RAP with contents of 100%, 50%, 30% and 15% in blends with RCA. This research also reports on the field performance of a pavement subbase constructed with untreated RAP at a field trial demonstration site.

Laboratory Experimentation Methodology

The laboratory experimental program involved the evaluation of the geotechnical characteristics of RAP and RAP/RCA blends. Samples of RAP and RCA for this research were collected from a recycling site at Victoria, Australia. The RCA and RAP collected for this investigation had a maximum particle size of 20 mm. Samples were obtained by bulk sampling of the recycled materials at the recycling site in 20 kg sample bags. Tests were subsequently undertaken following relevant ASTM, British Standards and Australian Standards, as appropriate.

The laboratory evaluation program included particle size distribution, modified Proctor compaction, particle density, water absorption, California Bearing Ratio (CBR), Los Angeles abrasion, pH, organic content, flakiness index, permeability and repeated load triaxial (RLT) tests. The RAP and RCA blends investigated were 100% RAP (100RAP), 50% RAP and 50% RCA (50RAP/50RCA), 30% RAP and 70% RCA (30RAP/70RCA), 15% RAP and 85% RCA (15RAP/85RCA) and 100% RCA (100RCA). The specialized RLT tests were also undertaken on 100RAP, 15RAP/85RCA and 100RCA blends.

Particle size distribution and hydrometer analysis tests were performed in accordance with AS 1141.11 (1996) and ASTM D 422 (1963) respectively. Particle density and water absorption tests were undertaken on both coarse (retained on 4.75 mm sieve) and fine (passing 4.75 mm sieve) fraction of the materials. In this study, the particle density and water absorption values of the samples were determined according to AS 1141.5 (2000a) and AS 1141.6.1 (2000b).

pH tests were performed in accordance with AS 1289.4.3.1 (1997). Organic content tests were performed in accordance with ASTM D2974 (2007a). The loss on ignition method was used to determine the organic content of the aggregates.

Hydraulic conductivity tests were performed in accordance with AS 1289.6.7.2 (2001). The samples were compacted at optimum moisture content to reach a minimum of 98% of maximum modified Proctor dry density. As the hydraulic conductivity of samples was comparably small, falling head method was used. The samples were saturated overnight with de- aired water before starting the test to make sure that the voids in the sample are fully saturated. Readings were recorded for at least 3 days to assure consistency in test results.

Flakiness index tests were performed in accordance with BS 812-105.1 (2000). Oven dried sample passed 63.0 mm and retained on the 6.3 mm were selected for testing. Since the maximum aggregate size of the tested material was 20 mm, three subdivisions of aggregate were prepared. Materials passed 20 mm and retained on 14 mm, passed 14 mm and retained on 10 mm, passed 10 mm and retained on 6.3 mm were the three subdivisions.

The Los Angeles abrasion test is the most widely specified test for evaluating the resistance of aggregates to abrasion and impact forces (Papagiannakis and Masad, 2007). Following the standard test method for resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles machine (ASTM, 2006), LA Abrasion tests were conducted on all blends.

Modified compaction effort was used to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the blends. The modified compaction tests were conducted by following the Australian standard AS 1289.5.2.1 (2003), which is similar to the ASTM-D1557 (2009).

California Bearing Ratio (CBR) test method followed the Australian standard AS 1289.6.1.1 (1998). The CBR tests were carried out on specimens subjected to modified Proctor compaction effort at the optimum water content and soaked for four days to simulate the worst case scenario.

Repeated Load Triaxial (RLT) test was conducted to determine the resilient modulus and permanent deformation of the recycled materials. In this investigation, the RLT test was performed according to the test method proposed by Vuong and Brimble (2000). The RLT testing by this method consists of two phases of testing, permanent strain testing and then resilient modulus testing (Austroads, 2000, Arulrajah et al., 2013c, Rahman et al., 2013). Permanent strain testing consists of three or four stages, each performed at different deviator stresses and a constant confining stress. The resilient modulus testing consists of sixty six (66) loading stages with 200 repetitions. In this test, the specimens were compacted to 98% modified maximum dry density (MDD) and tested at three target moisture contents of 70%, 80% and 90% of the modified optimum moisture content (OMC). The RLT test is considered as the laboratory method best suited for evaluation of dynamic characteristics of materials used in pavement bases/subbases.

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Field Testing Methodology

Following the completion of the laboratory evaluation tests, untreated 100RAP was used as a subbase material in nine pavement sections for a haul road at the recycling site operator's facility. 100RAP was selected as it was available in large stockpiles at the recycling site and there was interest from various parties to evaluate the field performance of untreated 100RAP in subbase layer.

Each of the pavement sections constructed was 80 m long and 4.75 m wide. The pavement sections comprised of a 200 mm thickness RAP subbase, overlying a subgrade with a design soaked CBR greater than 5%. After placement and spreading, the 100RAP material was graded to a uniform level using the controlled grader. A minimum 4 days dry-back period was applied for the 100RAP subbase in all pavement sections. Nuclear density checks were undertaken during the dry back period to measure the final compaction levels of the RAP subbase. Final levels of the subbase surface were also taken to confirm subbase thicknesses.

For the assessment of the geotechnical field performance of the 100RAP and their impact on subbase strength and stiffness, field testing was conducted at various locations after the placement of the 100RAP pavement subbase layer using a Nuclear Density Gauge (NDG) and Clegg Hammer (CH) 3 days after the placement of the subbase layers. It was therefore expected that the field moisture conditions at the time of testing would be lower than the optimum moisture conditions at the time of compaction, as the materials were delivered within the recycling site and haulage time was about 2 minutes.

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The Standard Clegg hammer consists of a 4.5 kg compaction hammer using a 457.2 mm drop height which is equipped with an accelerometer (ASTM, 2007b). The Impact Value (IV or CIV) is a dynamic force penetration property which relates to soil strength and may be used to set a strength parameter (ASTM, 2007b). Equation (1) is used to convert the Clegg Impact Value (CIV) to a field CBR value (Clegg, 1986).

$$\text{CBR}_{\text{Field}}\,(\%) = 0.06\,\text{CIV}^2 + 0.52\,\text{CIV} + 1 \qquad \text{Equation (1)}$$

To obtain a strength ratio which is defined as the ratio of CBR obtained in field (from Clegg hammer test) to the required CBR value (28% for this application); Equation (2) was used.

$$\text{Strength Ratio}\,(\%) = \frac{\text{CBR}_{\text{Field}} \times 100}{\text{CBR}_{\text{Required}}} \qquad \text{Equation (2)}$$

A nuclear density gauge was used to obtain the in-place density and water content of the compacted layers following the ASTM D6938 test method (ASTM, 2010). Equations (3) and (4) were implemented to obtain the moisture ratio and density ratio of the compacted base layer using the values measured by NDG and the values obtained from laboratory modified Proctor compaction tests (Vuong and Arulrajah, 2010):

$$\text{Moisture Ratio}\,(\%) = \frac{\text{Field Moisture Content} \times 100}{\text{Optimum Moisture Content}} \qquad \text{Equation (3)}$$

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$$Density\ Ratio\ (\%) = \frac{Field\ Dry\ Density \times 100}{Maximum\ Dry\ Density} \qquad \text{Equation (4)}$$

Results and Discussion

Laboratory Evaluation

Table 1 presents the geotechnical properties of 100RAP and the RAP/RCA blends. 100RCA results are indicated in the table for comparison purposes with 100RAP and the RAP/RCA blends.

The RAP blends tested were classified in Table 1 according to Unified Soil Classification System (USCS). For reference purposes, the grading of the blends and the grading ranges (i.e., the upper and lower limits) of the Standard specifications for type 1 gradation C material recommended in (ASTM, 2007c) for subbase materials are shown in Figure 1. It is noted that all blends chosen for this investigation had small amount of fines and moderately satisfy the guidelines for type 1 gradation C road subbase material.

Table 1 indicates that 100RAP had high water absorption values as compared to 100RCA. 100RAP was also noted to have a relatively high loss on ignition, which may be attributed to the presence of bitumen. Particle density of 100RAP is noted to be lower than that of 100RCA.

Based on the Dry density - Moisture content relationships, 50RAP/50RCA had the highest maximum dry density (MDD) of 19.9 kN/m^3 and 30RAP/70RCA had the lowest MDD of 19.03 kN/m^3 among the blends. The optimum moisture content (OMC) of all blends lie between 8.1% and 12.2%. The MDD or OMC did not show any trend with the percentage of RAP or RCA contents. However, the MDD varied by small values; maximum of 0.9 kN/m^3.

The pH readings of the blends, in Table 1, indicate that the RAP/RCA blends had higher pH values than 100RAP. The RAP/RCA blends also had a constant pH value. This could be due to the soluble calcium hydroxide formed during the hydration reaction from the residual cement in the RCA gone into solution, which raised alkalinity. However, the pH values of all blends were above 7 and this indicates that the blends are alkaline by nature.

Flakiness index values in Table 1 does not show any pattern of variation with the percentage of RAP content in the blends. However, it is worth noting that the addition of RAP increased the Flakiness indices of the blends. The Flakiness indices obtained in this investigation were below 40, which is recommended as the maximum limit for a subbase aggregate by Tam and Tam (2007).

Hydraulic conductivity values indicated in Table 1 did not vary with the percentage of RAP of RCA contents. Among the blends, the highest and the lowest hydraulic conductivity values of 7.45×10^{-7} and 3.3×10^{-8} m/s were obtained for 50RAP/50RCA and 100RCA respectively. These values can be described as low permeability.

Los Angeles (LA) abrasion values presented in Table 1 indicate no trend with the percentages of RAP and RCA contents in the blends. For majority of the blends, the LA abrasion values were slightly above the maximum limit of 35 recommended by the local state road authority for subbase materials and the value reported by Courard

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et al (2010). This indicates that some blends are not durable and should be used in pavement subbase layers with care.

CBR values of the blends are presented in Table 1 and are plotted in Figure 2 against the percentages of RAP and RCA contents. It is worth noting from Figure 2 that the CBR increased with decreasing RAP and increasing RCA content in the blends. This indicates that RCA is a higher quality recycled aggregate as compared to RAP, which is consistent to the findings of several authors (Arulrajah et al., 2013b, Piratheepan et al., 2013). This would furthermore justify why several road authorities internationally have specifications available for the usage of 100RCA in pavement subbases but not for 100RAP as well as the current requirement to stabilize RAP with cement or blending with other high quality aggregates (Taha et al., 2002, Hoyos et al., 2011, Puppala et al., 2012). Except for 100RCA, all the other RAP blends did not satisfy the local state road authority requirements for a lower subbase material, which requires a minimum CBR value of 80%. This indicates that RAP can only be used as an additive in limited proportions in blends with RCA.

In the Repeated Load Triaxial (RLT) tests, the materials were compacted to 98% modified proctor maximum dry density (MDD). The 100RAP, 15RAP/85RCA and 100RCA blends were tested at target moisture contents of 60-90% of the OMC. The RLT test result of permanent strain testing (variations of permanent strain and resilient modulus against number of load cycles) for the 15RAP/85RCA is plotted in Figure 3 and Figure 4. The resilient modulus values, from resilient modulus test with 66 stress stages, is presented in Figure 5. In the permanent deformation test (Figure 3 and 4), 50 kPa confining pressure was used, whereas, in the resilient modulus test

(Figure 5), the specimens were tested under 66 stress stages and each stage involved at least 50 cycles at the stress condition of specified repeated deviator stress and static confining stress and higher resilient modulus values were obtained for higher confining stresses. The results of permanent strain and resilient modulus values at the end of each test stages for the 100RAP, 15RAP/85RCA and 100RCA are given in Table 2. Table 2 also presents the typical results of traditional granular sub-base materials for comparison. For the structural design of pavements with the usage of a pavement design program, the resilient modulus is the key input parameter that needs to be specified for the study of base/subbase materials. The results as presented in Table 2 would be the important parameters to be used in the design software.

The 100RAP sample tested at a low moisture content of 55% failed during the early stage of RLT testing and consequently was found not to meet the requirements of a subbase material. The 100RAP sample at higher moisture contents was therefore not tested, as it was expected that this sample would also fail. This indicates that 100RAP cannot be used in subbases. RAP needs to be used in limited blends with higher quality recycled aggregates (such as RCA in this study) or stabilized with cement prior to use, as is the often used current practice. The results furthermore indicate that the recycled materials and RAP blends show sensitivity to moisture and produce higher limits of permanent strain and lower limits of resilient modulus particularly at the higher target moisture contents.

The 15RAP/85RCA blend was however found to meet the requirements of a subbase material at the lower achieved moisture contents of 60% to 83% of the OMC. The samples at the higher 88% of the OMC however failed in the later stages of the test. This higher level of 88% of the OMC however represents a worst case scenario. In reality, achieved moisture levels in the field will be lower than this and will be in the 60% to 75% range of the OMC levels as this is the normal operating field moisture content for most pavement materials. As expected the performance of the recycled materials was found to be affected by increasing moisture contents and the density level achieved in the compacted samples. The 15RAP/85RCA blend at achieved moisture contents of 59-78% of the OMC was found to meet the requirements of a subbase material with values comparably to that expected of typical quarry aggregates.

100RCA results are also indicated in Table 2 for comparison purposes. 100RCA was reported to perform satisfactorily at 98% MDD and at an achieved moisture content of 60% to 83% of the OMC, meeting the requirements expected for a pavement subbase material. The high resilient modulus values achieved for the 100RCA suggest that residual cementing action is occurring in the 100RCA samples. While this action may result in shrinkage cracks and some reflective cracking, it is unlikely to significantly affect the performance of the pavement layer over time (Arulrajah et al., 2013c). This is because the hydration process due to residual cement in RCA will be considerably slow and the slow hydration process will produce minimal shrinkage effects (Chakrabarti and Kodikara, 2005).

The laboratory evaluation study indicated that RAP/RCA blends when used with a low 15% RAP content met the Repeated Load Triaxial requirements for permanent strain and resilient modulus for usage in pavement subbase layers at achieved moisture contents of 59-78% of the OMC. However the CBR results for this blend were marginally lower than the requirements. The laboratory results for the higher contents of RAP in the RAP/RCA blends did not meet pavement subbase requirements.

Field Evaluation

The earlier phase of laboratory evaluation of 100RAP indicated that it did not meet the local road authorities' requirements for usage in pavement subbase layers, particularly in terms of RLT and CBR requirements. Nevertheless, the field trial pavement constructed was for a private haul road in the recycling operator's site and as such did not have to meet the specified requirements of the local road authorities. RAP was furthermore readily available in large stockpiles at the recycling site and there was interest from various parties to evaluate the field performance of 100RAP in pavement subbase layers, and as such the pavement subbase was constructed with 100RAP.

Direct transmission method of nuclear density and moisture testing was conducted on the granular base and subbase layers after the construction of each layer at 10 meter intervals along 2 wheel paths for each of the pavement sections. Field density values were calibrated by using oven moisture measurements obtained from the same locations as moisture contents attained by using the nuclear gauge. Samples of 100RAP were obtained from the subbase layers from each section placed on construction and subsequently tested in the laboratory to obtain their corresponding MDD and OMC.

Table 3 presents the mean values of density and moisture content results for the 100RAP subbase from Nuclear Density Gauge and field samples at the various pavement sections. The field densities for RAP were in the 20 kN/m^3 range. The

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results indicate that density ratios in individual sites varied in the range of 94 to 97 % MDD. The results indicated that for the various sections, the average moisture contents obtained were in a similar range for the various pavement subbase sections varying from 4.9% to 5.5%.

Road authorities require material to have minimum mean values of density ratio of 98% for subbase materials for light duty pavements. Based on this requirement, the 100RAP subbase layer was found to be marginally below these requirements. Road authorities also require material during compaction to have a moisture content of not less than 85% of optimum during compaction and, after completion of compaction of a layer. The moisture content of the material in the layer shall be maintained at a moisture content of not less than 85% of optimum until test rolling has been completed. Based on the results in construction of the subbase for the RAP pavement trial complied with target minimum moisture content requirement of 85% OMC.

The results from the Clegg Hammer tests results were analyzed to determine CBR values of the various pavement sections as well as to determine the strength ratios after field compaction. Figure 6 presents the Clegg hammer results for CBR for the various pavement subbase sections with 100RAP. The CBR values calculated from Clegg Hammer results for 100RAP appear to vary significantly within each pavement section and between pavement sections. The Clegg Hammer tests indicate 100RAP did not meet the minimum soaked field CBR of 80% for a subbase material in the various sections as would be required by a local road authority. Based on the field and laboratory testing results, 100RAP, had insufficient strength requirements to meet the local road authority pavement subbase requirements.

Conclusions

Reclaimed Asphalt Pavement in pavement subbase was assessed by means of initial laboratory testing and subsequent field testing in a demonstration site. An extensive suite of geotechnical laboratory tests were undertaken on RAP with contents of 100%, 50%, 30% and 15% in blends with RCA.

The laboratory evaluation study indicated that RAP/RCA blends when used with a low 15% RAP content met the Repeated Load Triaxial requirements for permanent strain and resilient modulus for usage in pavement subbase layers at achieved moisture contents of 59-78% of the OMC. However the CBR results for this blend were marginally lower than the requirements. The laboratory results for the higher contents of RAP in the RAP/RCA blends did not meet pavement subbase requirements. Based on the field and laboratory testing results, 100RAP, had insufficient strength requirements to meet the local road authority pavement subbase requirements.

It is to be noted that as this field trial pavement subbase constructed was for a private haul road, and as such did not have to meet the local road authority requirements. RAP and RAP/RCA blends, though found in this study to be not fully compliant with the local road authorities requirements for pavement subbases, could be potentially considered for lower traffic usage such as haul roads and footpaths.

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Table 1. Geotechnical properties of RAP/RCA blends

Sample Description	**100RAP**	**50RAP/ 50RCA**	**30RAP/ 70RCA**	**15RAP/ 85RCA**	**100RCA**
Recycled Asphalt (RAP) by weight (%)	**100**	**50**	**30**	**15**	**0**
D_{10} (mm)	0.46	0.2	0.16	0.36	0.24
D_{30} (mm)	1.9	2.7	2.4	1.7	1.4
D_{50} (mm)	4	5.8	5	5.1	5
D_{60} (mm)	5.3	9.7	9	7.5	7.3
Coefficient of uniformity	11.5	48.3	56.2	20.83	30.4
Coefficient of curvature	1.48	3.75	4	1.07	1.12
Gravel content (%)	45.5	46.4	44.8	50	49.8
Sand content (%)	54.5	53.6	55.2	50	45.7
Fines content (%)	3.4	1.7	3.2	0	3.6
USCS classification	SW	SP	SP	SW-GW	GW
Particle density – Coarse fraction(Mg/m^3)	2.4	2.19	2.15	2.9	2.76
Particle density – Fine fraction (Mg/m^3)	2.4	1.67	1.80	2.5	2.65
Water absorption – Coarse fraction (%)	8.6	6	5.72	8.4	4.66
Water absorption – Fine fraction (%)	22.4	8.13	7.40	18.6	9.75
Loss on Ignition (%)	5.1	2.45	4.50	2.55	2.25
pH	7.6	11.37	11.41	11.81	11.49
Fine content (%)	3.4	1.7	3.2	6.46	3.6
Flakiness index	22.34	33.14	37.90	37.0	11
Hydraulic conductivity (m/s)	3.5×10^{-7}	7.45×10^{-7}	1.75×10^{-7}	5.8×10^{-7}	3.3×10^{-8}
Los Angeles abrasion loss (%)	42	33	36	39	28
California Bearing Ratio (%)	30-35	39	46	66	118
Max dry density - modified compaction (kN/m^3)	2.00	2.03	1.94	1.95	1.96
Optimum moisture content - modified compaction (%)	8.1	11.5	12	12.2	12

Table 2. Range of permanent strain and resilient modulus from permanent strain testing (Phase 1) for RAP-RCA blends at the end of each loading

Material	**Permanent Strain Testing**	**Target Moisture Content (% of OMC)**	**Achieved Moisture Content (% of OMC)**	**Target Dry Density (98% of MDD) (Mg/m^3)**	**Achieved Dry Density (Mg/m^3)**	**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**
100RAP	Permanent strain (micro strain)	60	55	1.96	1.97	Failed	Failed	Failed
	Resilient modulus (MPa)	60	55	1.96	1.97	Failed	Failed	Failed
15RAP/85RCA	Permanent strain (micro strain)	90	88	1.91	1.90	8866	Failed	Failed
	Permanent strain (micro strain)	75	78	1.91	1.89	1972	2768	3298
	Permanent strain (micro strain)	60	59	1.91	1.90	878	1392	1823
	Resilient modulus (MPa)	90	88	1.91	1.90	232	Failed	Failed
	Resilient modulus (MPa)	75	78	1.91	1.89	412	611	728
	Resilient modulus (MPa)	60	59	1.91	1.90	587	774	928
100RCA	Permanent strain (micro strain)	90	83	1.92	1.91	-	4471	5669
	Permanent strain (micro strain)	80	71	1.92	1.91	-	2426	2956
	Permanent strain (micro strain)	70	60	1.92	1.90	1585	2079	2532
	Resilient modulus (MPa)	90	83	1.92	1.91	-	342	357
	Resilient modulus (MPa)	80	71	1.92	1.91	-	660	697
	Resilient modulus (MPa)	70	60	1.92	1.90	695	713	716
Typical Quarry Material (Arulrajah et al., 2011)	Permanent strain (micro strain)	90	90	-	-	7000-15000	10000-20000	10000- >20000
	Permanent strain (micro strain)	80	80	-	-	5000-10000	7000-15000	10000- >20000
	Permanent strain (micro strain)	70	70	-	-	3000-10000	4000-15000	5000-20000
	Resilient modulus (MPa)	90	90	-	-	125-300	150-300	175-300
	Resilient modulus (MPa)	80	80	-	-	150-300	175-300	200-300
	Resilient modulus (MPa)	70	70	-	-	175-350	200-400	225-400

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Table 3. Subbase layer: Mean values of density and moisture content results from Nuclear Density Gauge and field samples.

Section Number	**Dry Density –Field (Mg/m^3)**	**MDD – Laboratory (Mg/m^3)**	**Density Ratio (%)**	**Moisture Content-Field (%)**	**OMC - Laboratory (%)**	**Moisture Ratio (%)**
1	2.08	2.16	96.3	4.9	6.5	75
2	2.08	2.16	96.3	5.2	6.5	80
3	2.09	2.16	96.8	5.5	6.5	85
4	2.05	2.16	94.9	5.5	6.5	85
5	2.05	2.16	94.9	5.3	6.5	82
6	2.03	2.16	94.0	5.3	6.5	82
7	2.04	2.16	94.4	5.4	6.5	83
8	2.05	2.16	94.9	5.1	6.5	78
9	2.09	2.16	96.8	5.5	6.5	85

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Figure 1

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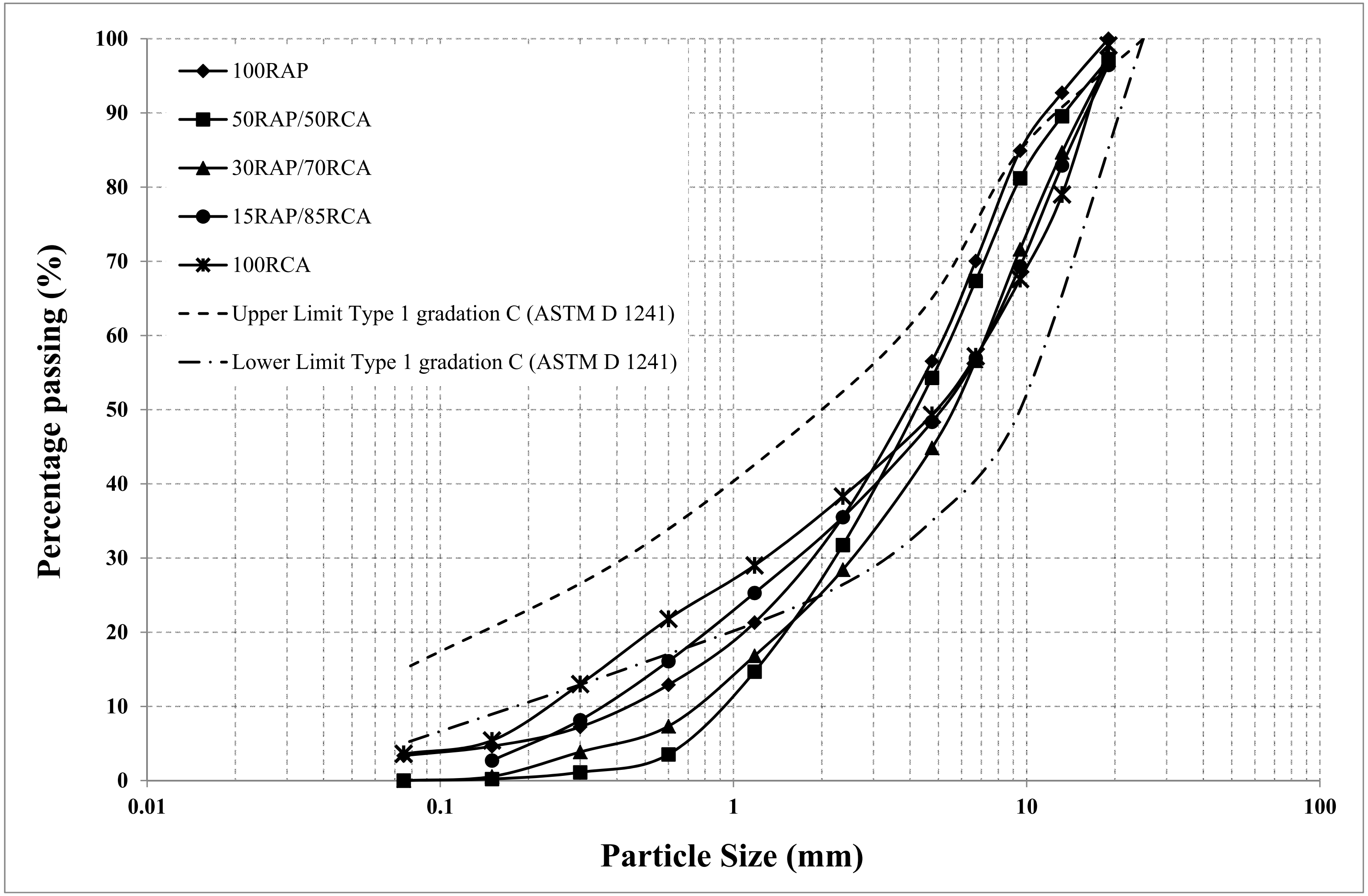

Figure 2

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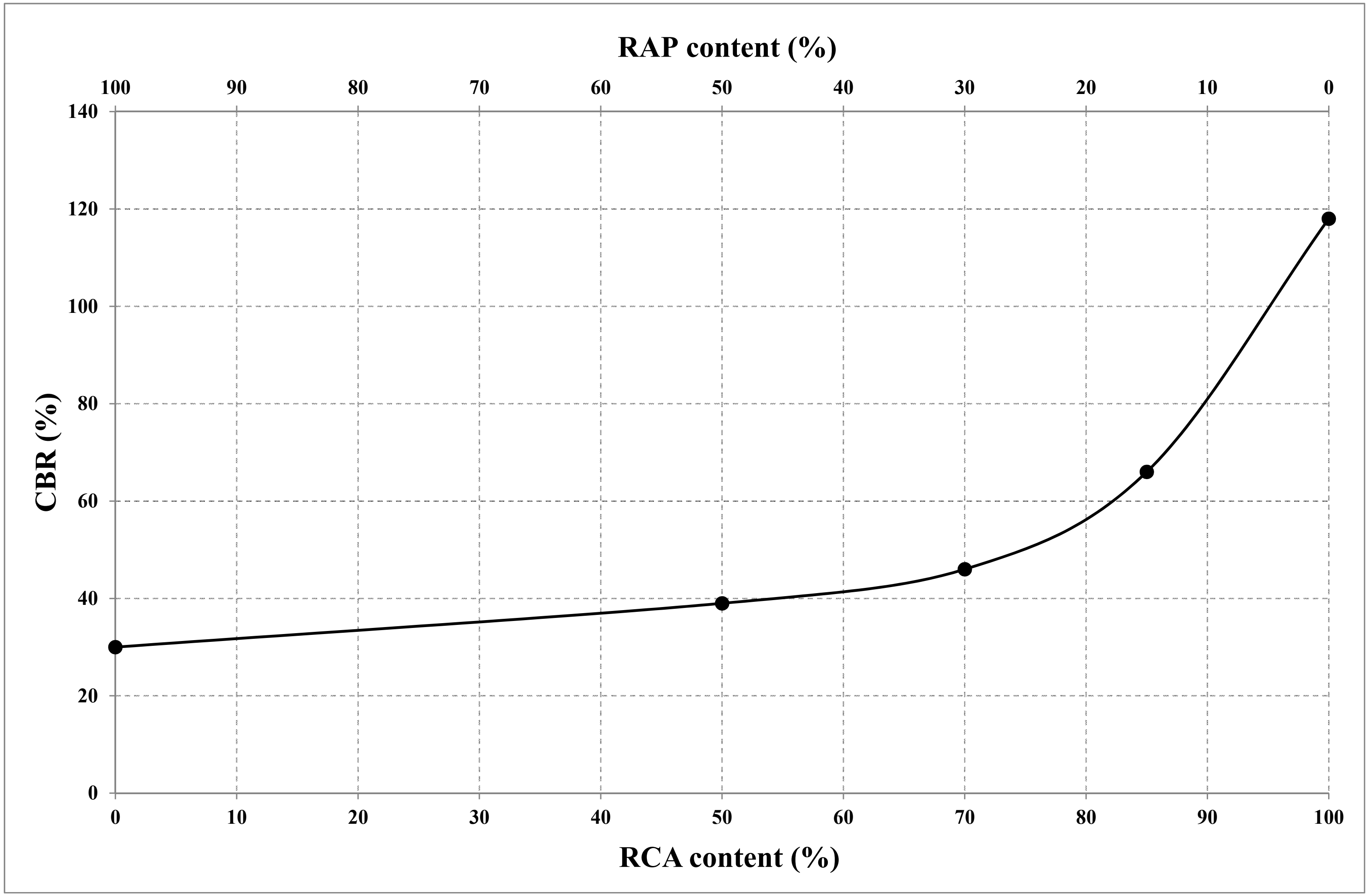

Figure 3

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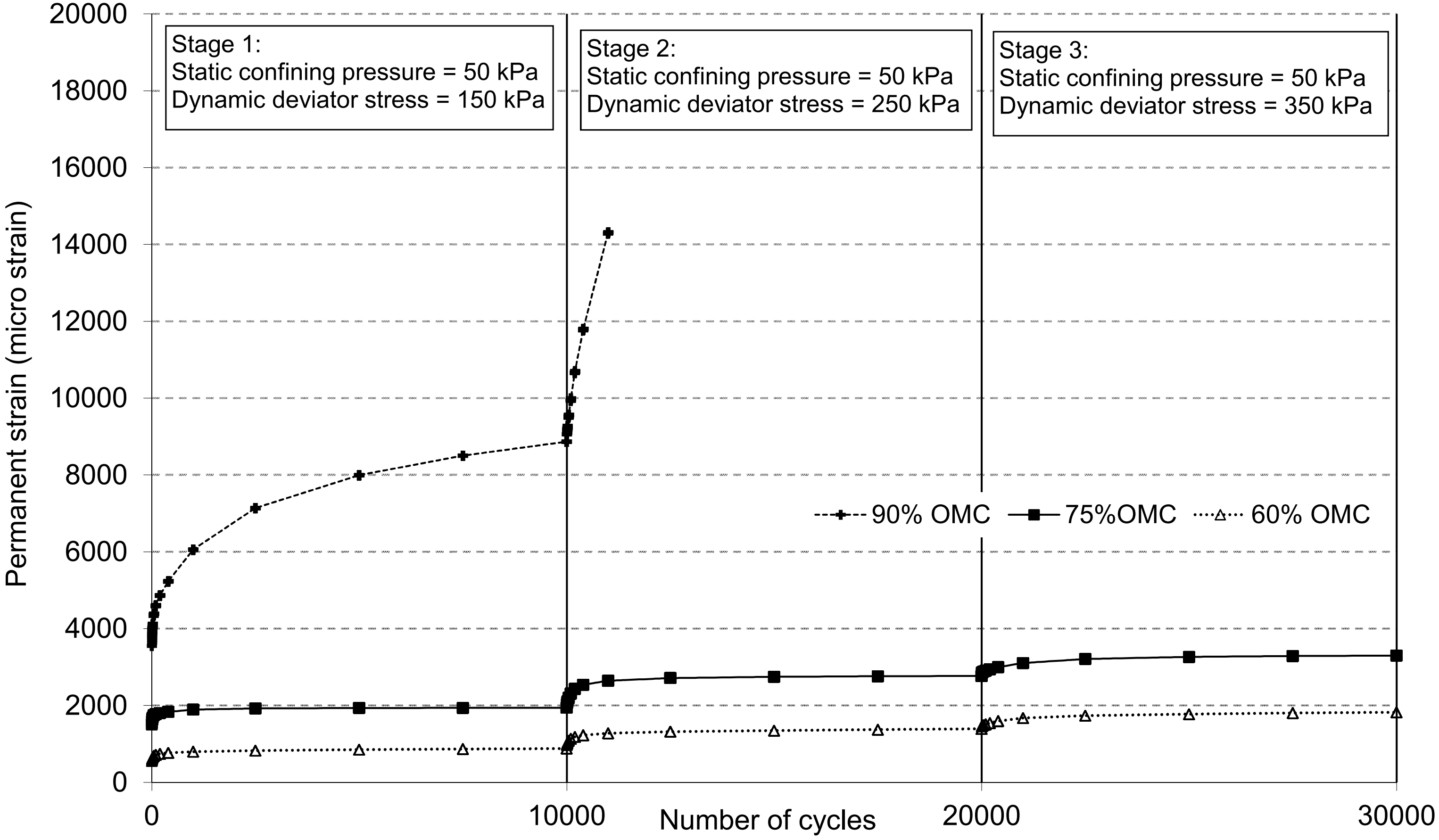

Figure 4

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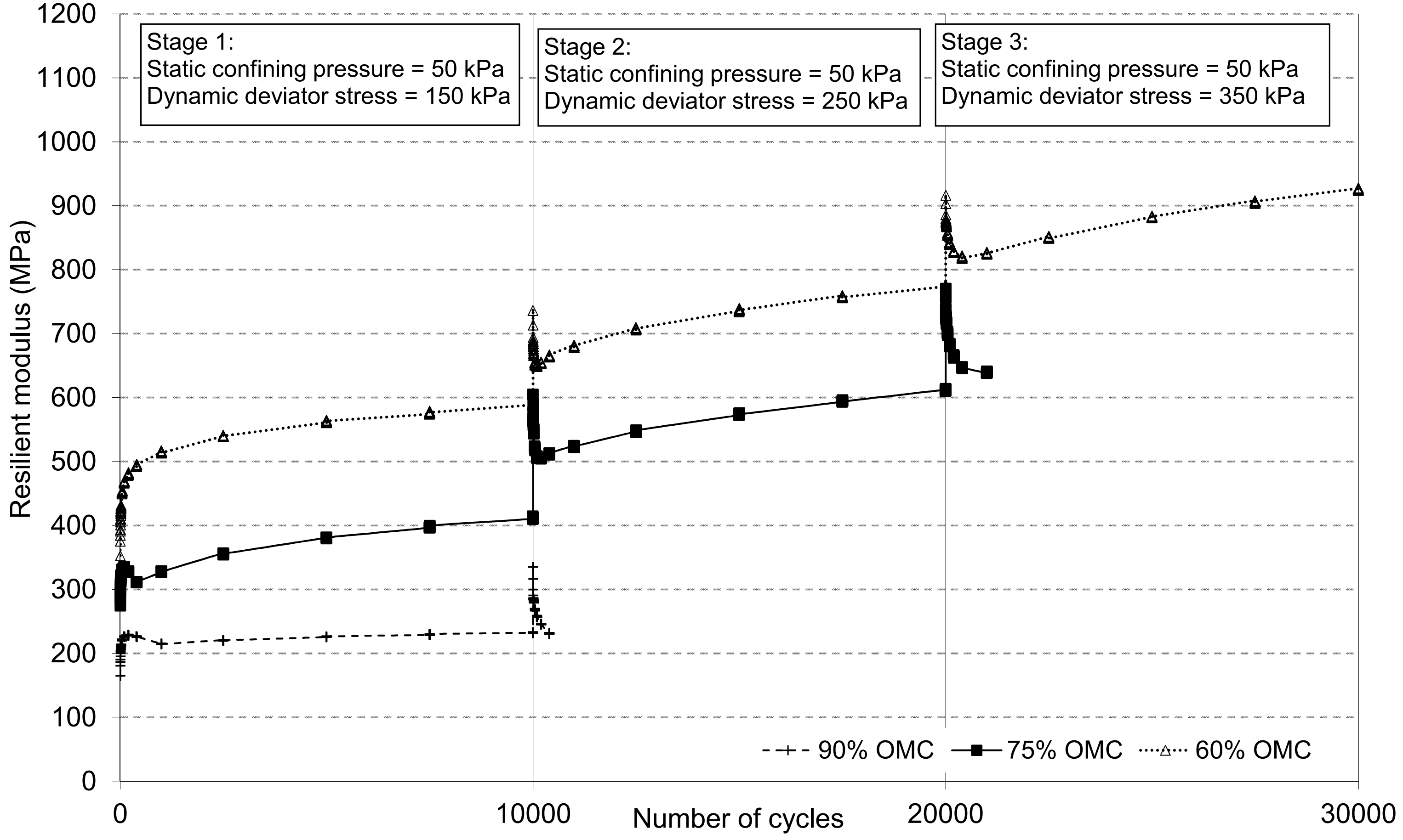

Figure 5

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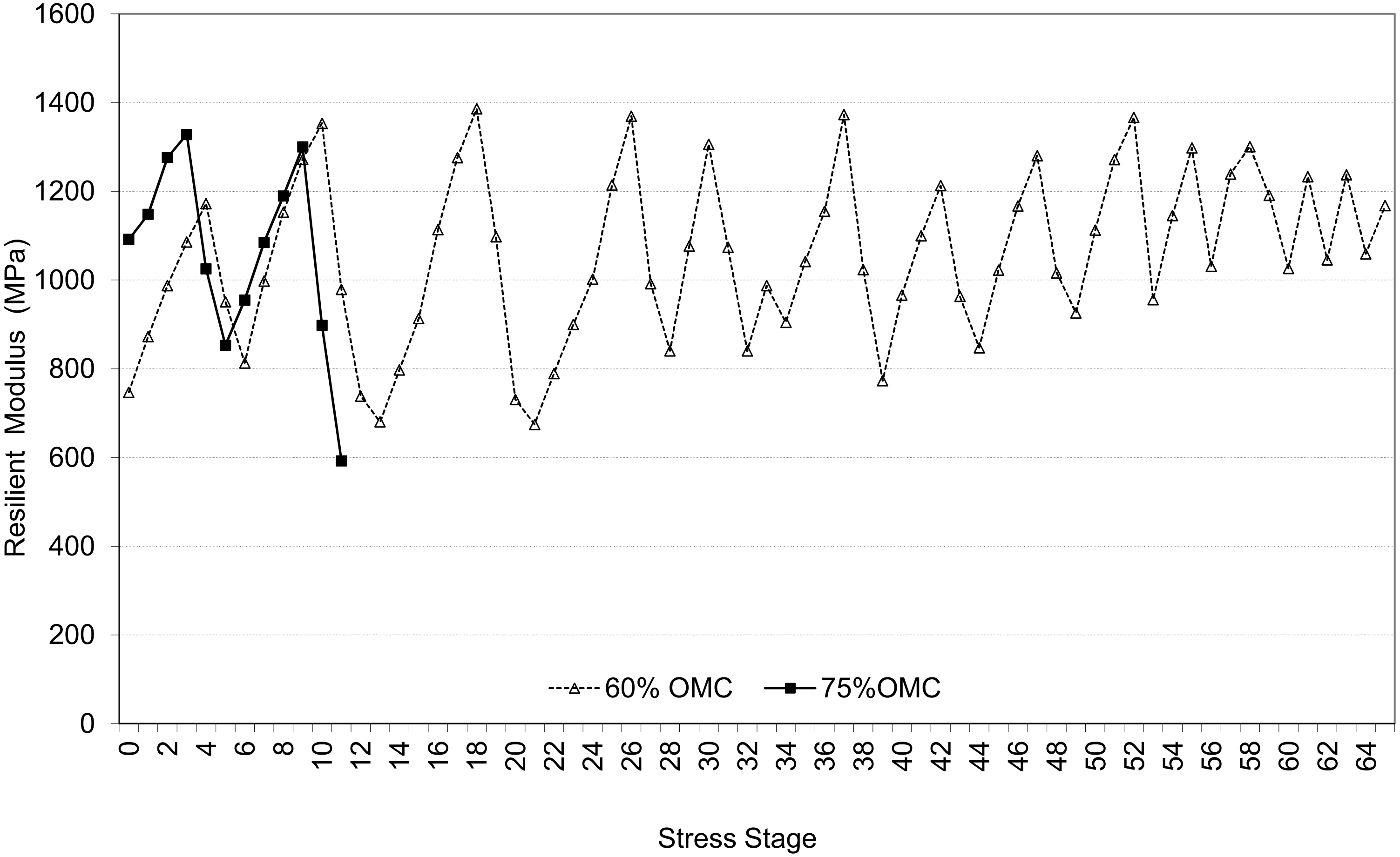

Figure 6

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