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Assessment of RCA with RAP materials for pavement applications

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Abstract. Demolished concretes are being recycled to produce recycled concrete aggregates (RCA) in different scales around the world. Therefore, applications of RCA as a construction material are being popular by replacing conventional materials. Many research studies have confirmed the potential use of RCA to be applied as an unbound pavement material. However, presence of constituents such as reclaimed asphalt pavement (RAP) in RCA effects on its native properties. Therefore, this study evaluates performance characteristics of RCA with RAP under dynamic loading condition. A series of “repeated load tri-axial (RLT)” test was conducted on RAP blended RCA samples to evaluate the elastic and plastic deformation characteristics with increase of load cycles. The elastic deformation was characterised by resilient modulus and slightly dropped with increase of RAP from 0, 5, 10 to 15% in RCA. Further, it observed a trend of small increase of the plastic deformation of the RCA with the increase of RAP portion. However, presence of RAP up to about 15% in RCA did not significantly affect on the accumulation of permanent strain.

1. Introduction

Recycling and reusing of C&D waste creates many economic and environmental benefits while enhance the sustainability in construction material industry. Concrete is the major component of total among the various types of C&D waste which is greater than 80% in Australia [1]. Therefore, recycling the concrete to produce the crushed aggregates is one of the sustainable outcomes of waste management. Utilization of recycled concrete aggregates in granular layers in flexible pavements is a viable alternative since road are typically demanded a huge volume of crushed aggregates. The reclaimed asphalt pavements (RAP) is one of the major constituents in RCA in Australia and its influence on the properties of RCA has not been completely investigated. The bitumen in the RAP is sensitive on the temperature, thus could be made an impact on physical and mechanical properties of RCA. Therefore, Road authorities do not rely on consistent properties of RCA due to insufficient technical information of the effect of RAP on RCA.

Investigations on the strength properties of RCA have revealed feasibility of RCA to be used as unbound pavement materials under different conditions [2, 3]. However, Investigations on the RCA and RAP together are very limited. A comprehensive study was conducted by [4] to investigate the effect of RAP on RCA to be used as unbound pavement material in subbase layers. The results introduced to allow only up to 15% of RAP to be mixed in RCA to assure the required performance. The study was further emphasised not to use 100% of RAP as subbase course material. The results of



this study were confirmed by the findings of [5]. A detailed study on RCA and RAP was conducted by [6] to investigate the confined strength and unconfined strength of RAP blended RCA specimens and revealed a gradual decrease of strength in RCA when increase the RAP portion.

Performance characteristics of pavement materials which are the elastic and plastic deformation need to be investigated under the dynamic load conditions prior to their applications. RCA has been subjected to such experiments and revealed comparable performance characteristics. The research findings have revealed that the physical properties of RCA such as particle size distribution, degree of compaction, degree of saturation and presence of constituents have a greater influence on the elastic and plastic deformation of RCA [3, 7-9].

RCA itself has recorded inconsistent properties as a construction material due to the presence of cement fines, different qualities of parent aggregates, presence of minor constituents such as bricks, glass etc., in different regions [9-11]. In addition, RAP also presence in RCA as a major constituent which mixed with RCA at the recycling process. Therefore, investigations are needed to determine the effect of RAP as a constituent on the properties of RCA and, limited past studies are recorded [4, 12, 13]. This study was focused to investigate the influence of RAP on the performance characteristics of RCA as a granular pavement material. The study was planned to conduct a series of repeated load tri-axial (RLT) test to analyse the elastic and plastic deformation characteristics under dynamic load condition. The elastic response of the specimens was analysed by the behaviour of resilient modulus and plastic response was characterised by the accumulation of vertical strain of the RAP mixed RCA specimens with the number of load cycles.

2. Materials

Recycled concrete aggregates (RCA) and reclaimed asphalt pavements (RAP) were obtained from a concrete recycling plant in Queensland, Australia. Figure 1 (a) and (b) show pictures of the samples of RCA and RAP respectively.



Figure 1. (a) Recycled concrete aggregates-RCA (Scale 1:5) (b) Reclaimed asphalt pavement-RAP (Scale 1:3.2)

Physical properties of the RCA and RAP were extracted from the [6] since same materials were subjected to performance test in this study. Figure 2 shows the Particle size distribution curves of RAP and RCA materials with upper and lower limit of the standard base layer materials. Physical properties of RCA and RAP are shown in Table 1 and Table 2 respectively and the values present as reference for the purpose of comparison in similar studies in future. The descriptions of these properties have been presented in the previous publication of [6].

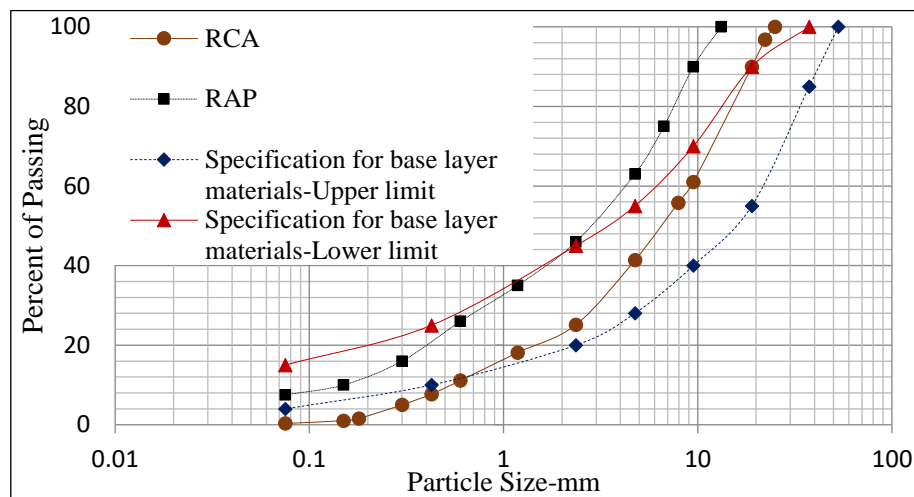


Figure 2. PSD curves of the RAP and RCA with upper and lower limit curves of standard base layer materials

Table 1. Physical properties of RCA [6]

Property	Values	Standard granular pavement material
Liquid Limit (LL) [%]	21.00	Maximum 25 [14]
Plasticity Index (PI)	5.40	Maximum 6 [14]
Linear Shrinkage (LS) [%]	1.00	Maximum 3.5 [14]
Water absorption (particles > 4.25 mm) [%]	5.35	<10 [9]
Water absorption (particles < 4.25 mm) [%]	6.50	<10 [9]
Specific gravity (Gs)	2.64	2.85 [15]
Maximum dry density (MDD) [g/cm ³]	1.75	>1.79 [9]
Optimum moisture content (OMC) [%]	13.20	8-15 [9]
California Bearing Ratio (4 days soaked) [%]	90-95	> 80% [14]

Table 2. Physical properties of RAP [6]

Property	Values	Standard test method
Binder (bitumen) content [%]		
Solvent extraction method	3.87	[16]
Ignition method	4.81	[17]
Specific gravity	2.59	[18]
Water absorption (particles < 4.25 mm) [%]	2.85	[18]
Water absorption (particles > 4.25 mm) [%]	2.81	[19]

3. Methodology

Test programme was designed to conduct Repeated load tri-axial (RLT) test to investigate the performance characteristics of RAP mixed RCA samples. RAP was mixed in RCA in different ratios by weight and shown in Table 3 with new sample names.

RLT tests were conducted under two test series as shown in Table 4 to determine the resilient and residual properties of the samples shown in Table 3. Tests were conducted in 2 different water contents. Water content-1 was selected as the corresponding optimum moisture contents to evaluate the performance at high moisture level. Water content-2 was the corresponding moisture levels at the degree of saturation of 60% of all the specimens. 60% of DoS was to represent the water content which is applied to compact the granular materials when the unbound granular layers are constructed [20].

Table 3. Sample names with the mix ratio of RCA and RAP

Blended Sample Name	RCA (% by weight)	RAP (% by weight)
RM1-100/RAP0	100	0
RM1-95/RAP5	95	5
RM1-90/RAP10	90	10
RM1-85/RAP15	85	15
RM1-80/RAP20	80	20

Materials were dried in oven overnight and cooled to room temperature before mix with water. The water mixed materials were kept in sealed containers for about three hours prior to the compaction and compacted samples were again kept in sealed containers for four days as it was revealed as the required curing time for the compacted RCA specimens [21]. Samples were compacted at their corresponding maximum dry densities (MDDs). RLT test were performed as the standards of QDTMR (Q137-Permanent deformation and resilient modulus of granular materials [22]) and Each test was run for 50,000 load cycles.

The obtained results of elastic deformation behaviour of the samples then evaluated with resilient modulus values. It was compared the design specifications of resilient modulus of base layer materials which use in pavement designing and assessed the feasible applications.

The plastic strain values were evaluated under limited shakedown concept to determine the behaviour of accumulation of plastic deformation. Results used to rank the samples and to assess the effect of RAP on RCA on the formation of permanent deformation.

Table 4. Repeated load tri-axial test programme

Sample Name	Confining pressure- kPa	Vertical stress- kPa	Test Series for Water content- 1 (OMC)	Test Series for Water content-2 (DoS-60%)	MDD- t/m ³	No: of load cycles
RM1-100/RAP0	125	750	13.2 %	11.62 %	1.748	50000
RM1-95/RAP5	125	750	12.2 %	10.81 %	1.785	
RM1-90/RAP10	125	750	12.7 %	10.74 %	1.785	
RM1-85/RAP15	125	750	12.3 %	10.58 %	1.789	
RM1-80/RAP20	125	750	12.9 %	10.55 %	1.789	

4. Results and discussions

4.1 Effect of RAP and moisture content on plastic properties of RCA

Minimize the formation of rut depth in pavement structure is the key aspect in pavement designing. Prediction of rutting in flexible pavement is extremely complex since it basically depends on the quality of the base and subbase materials as well as the environmental conditions (e.g. Freezing/thawing, flooding, natural drainage system etc.). Therefore, examine the plastic properties of the pavement materials under dynamic load condition is the foremost factor to understand and assess the behaviour of materials in pavement rutting [23].

Figures 3 and 4 illustrate the accumulation of plastic deformation of the five RCA samples at OMC and 60% of DoS level within 50,000 of load cycles. Rapid plastic deformations of the five samples were observed due to the rapid settlements at the initial cyclic loads. The settlements were occurred due to the re-compaction and densification at both moisture levels. Size of the initial settlement was high with increasing the RAP portion. Effect of RAP on the densification of the compacted samples significantly noticed with 20% of RAP at the both moisture levels and presence of RAP up to about 15% in RCA did not show a significant influence on the initial stabilization. The densification effect was high on deformation of the specimens at the initial load cycles due to the reorientation of particles [24]and this can be minimized by applying high effort on compaction of RCA.

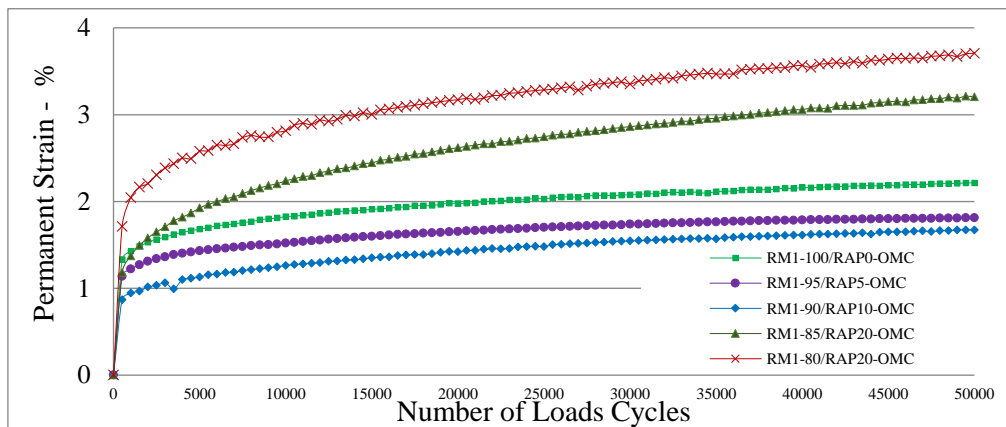


Figure 3. Permanent strains of RAP mixed RCA samples at OMC within 50,000 load cycles

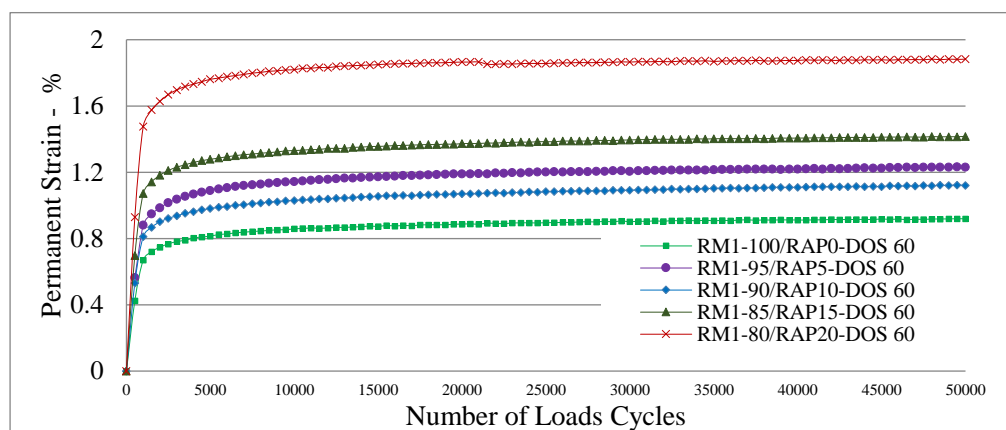
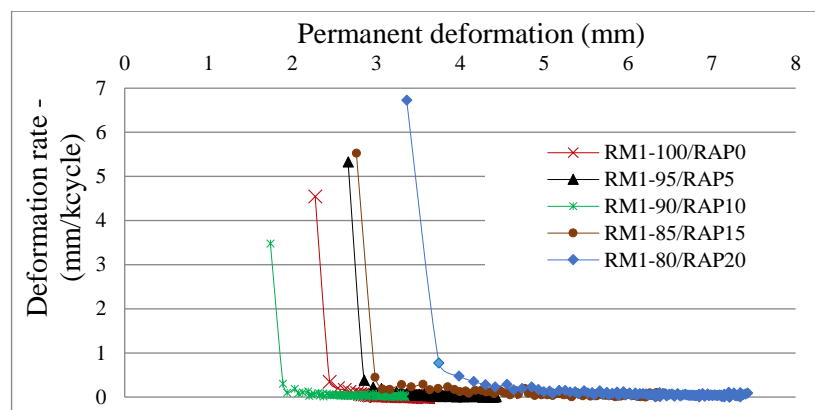


Figure 4. Permanent strains of RAP mixed RCA samples at 60% of DoS within 50,000 load cycles

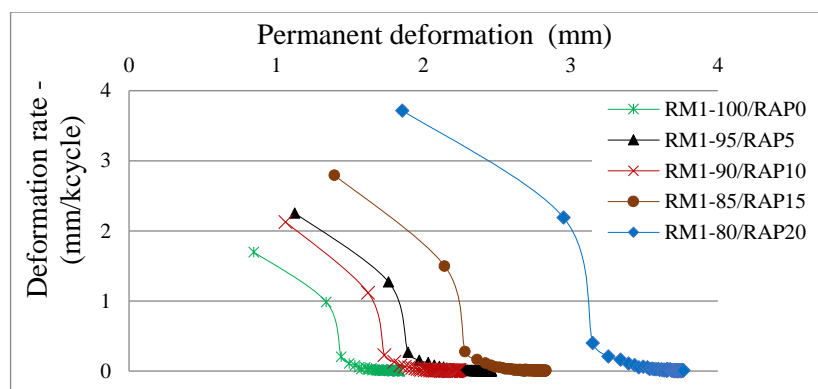
According to the deformation curves in Figure 3 the accumulated plastic strains of the samples of RM1-100/RAP0, RM1-95/RAP5, and RM1-90/RAP10 fluctuated within a small range of 1.5-2% indicating a continuous decrease of the rate of deformation consequently, highlights a negligible effect of RAP when the quantity was small in RCA. The specimens of RM1-85/RAP15 and RM1-80/RAP20 exhibited comparatively higher deformation and the rates of strain accumulation were being still increased at the 50,000 load cycles. Figure 5 (a) further illustrates the rates of deformation with the accumulation of vertical depth after initial settlement of the specimens at OMC. The specimens had high deformation rates and greater initial settlements at the beginning of load cycles. A rapid drop of the rate of deformations within a small range of rut depth were exhibited in all the specimens at their OMC values. After rapid settlements, the rates of deformation approached zero value indicating a promising sign of stiffening the compacted RCA with more load cycles.

According to the figure 4, the specimens mixed with 20% of RAP (RM1-80/RAP20) still showed the highest deformation at the 60% of DoS level. In contrast, it has significantly noticed that RCA mixed with 15% of RAP (RM1-85/RAP15) has considerably decreased its plastic deformation at 60% of DoS level than OMC (DoS=68%). However, five samples have given appreciable results in accumulating their plastic deformation at the 60% of DoS level. Ultimately, all the specimens exhibited below 2% of permanent strains within 50,000 load cycles. Figure 5(b) further illustrates the rate of deformation of the specimens with formation of permanent deformation at the 60% of DoS level. Unlike the Figure 5(a) the curves do not exhibit rapid drop of deformation rates at the beginning of load cycles. All specimens show a gradual decrease of deformation rate up to a certain level and there after a rapid drop were indicated. After accumulation of permanent deformations which is less

than 4.00 mm, all specimens lean towards to stabilize with gradual decrease of deformation rates which approached zero. Therefore, it revealed the hardening of the accumulation of plastic strain within a small range of permanent deformation at the 50,000 load cycles.



(a)



(b)

Figure 5. Rate of permanent deformation versus permanent axial deformation at (a) optimum moisture contents and (b) DoS = 60% of the RAP mixed RCA samples

Fives RCA samples illustrated great performance in terms of permanent deformation at the 60% of DoS level. More water at the corresponding OMC values has adversely affected on gaining of permanent strain as well as on the rate of strain accumulation at the end of 50,000 load cycles. More water in the pores of compacted specimens causes excess pore water pressure and lowers the shear resistance and decrease the stiffness. Water at 60% of DoS seems to be the adequate moisture contents to positively impact on gaining high stiffness to reduce the plastic deformation under dynamic wheel load. According to the Vuong and Hazell's [25] interpretation on plastic deformation behaviour, first three specimens (RM1-100/RAP0, RM1-95/RAP5, and RM1-90/RAP10) could be defined as “Stable” and the other two specimens (RM1-85/RAP15, RM1-80/RAP20) as “Unstable” at the optimum moisture contents. In contrast, all the samples were in the “Stable” state at the 60% of DoS level which satisfied the requirement for base layer material for the pavements subjected to heavy traffics (10^7 ESA).

It is important to highlight that the net accumulation of permanent axial deformation has become sensitive on the increase of RAP portion. Although, it is not much significance at the little potion of RAP up to about 15% and it can be observed a trend of high deformation when the RAP portion over 15% in RCA.

4.2 Effect of RAP and moisture content on elastic properties of RCA

Figure 6 shows the resilient modulus (M_r) results of the five samples at the corresponding OMCs and 60% of DoS levels at the end of 50,000 load cycles. The samples exhibited a gradual decrease of M_r but, within a small range at both moisture levels with increase of RAP. However, it illustrates the trend of decreasing the M_r with high portion of RAP in RCA. More RAP materials supply more medium size particles in RCA samples which the gradation adversely effects on compaction and there by lower the stiffness. Further, Thom and Brown [26] explained lubricating effect on particles which makes an adverse impact on resilient behaviour due to the lower inter-particle contact. The similar effect can be expected in bitumen coated RAP particles with hydrophobic surface. These particles' surface made such a lubricating effect at the wet condition and more RAP particles contribute more surface area with bitumen coat and lubricating effect increases in the compacted specimens.

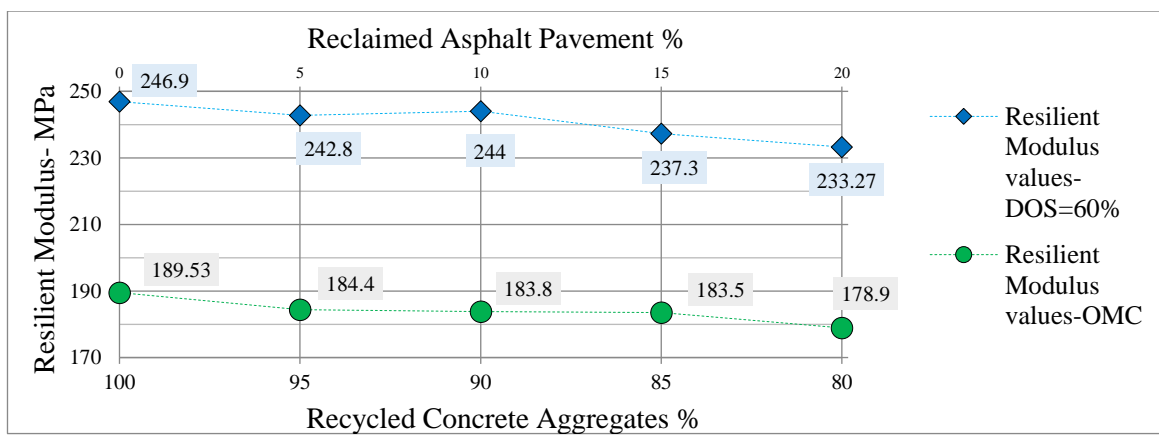


Figure 6. Resilient modulus values of the RAP mixed RCA samples at OMC and 60% of DoS level at the end of 50,000 load cycles

Poor performance observed at the high moisture contents at OMCs compared to the low moisture content (60% of DoS) since excess pore water pressure generates with more moisture and decline the shear resistance. Stiffness of the compacted specimens has reduced while the shear resistance was weak and deform more elastically resulting low resilient modulus. Furthermore, samples exhibited increasing of M_r at the low moisture content (60% of DoS) as shown in figure 7 while the M_r curves at OMCs steadily behaved as shown in figure 8. Continuous increase of M_r depicts the decreasing of elastic deformation of the RCA specimens at 60% of DoS. Therefore, elastic deformation of the five samples interpreted “Stable” state and further high stiffness and consequently high resilient modulus can be predicted with more load cycles beyond 50,000.

Some of the materials attribute their resilient behaviour such that become to steady state with a decreasing rate of their M_r while some of the pavement materials become to steady state with increasing rate of M_r . Although, the tested RCA samples exhibited low M_r values (range of 233–247 MPa at 60% of DoS) than some of high-quality base layer materials, the shapes of the M_r curves are promising sign of reducing the elastic deformation with more load cycles. Thus, it can be predicted gaining of high M_r values with more load cycles beyond the tested value of 50,000 load cycles.

Australia has introduced specific standard values of resilient modulus for normal standard and high standard base layer materials for structural design of pavements [27]. The standard guidelines of pavement structural designs have recommended minimum M_r as 150 MPa for the normal standard base layer materials and 210 MPa for the high standard base layer materials [27]. The obtained M_r of the five RCA samples exhibited greater M_r than the required minimum value of normal standard base materials at the 68% of DoS (OMCs) while the M_r values were greater than the minimum value of high standard base layer materials at the 60% of DoS. However, the presented M_r values of the RCA samples were obtained at the 50,000 load cycles. The shapes of curves of M_r depict an increasing rate

of M_r at the end of the 50,000 load cycles and can be predicted greater M_r values with more load cycles beyond 50,000.

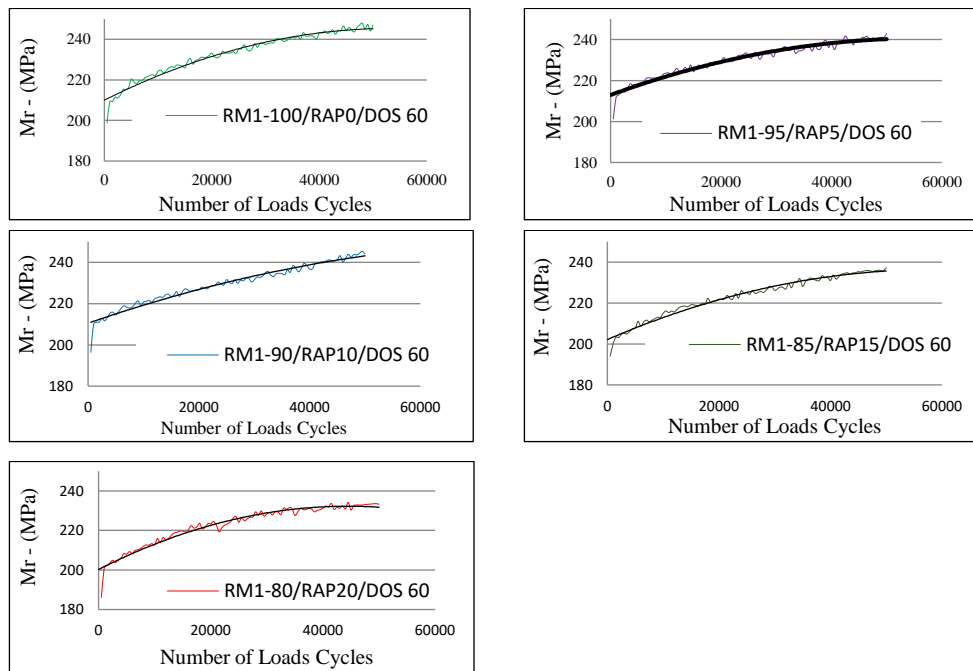


Figure 7. Resilient behaviour of the RAP mixed RCA samples at 60% of DoS level

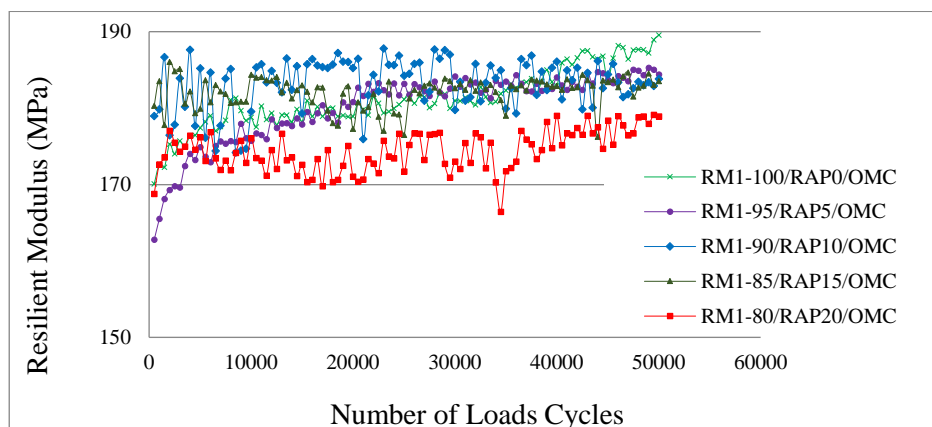


Figure 8. Resilient behaviour of the RAP mixed RCA samples at OMC levels

5. Conclusions

This study was carried out to investigate the performance characteristics of RCA with and without RAP material at two different water contents. The conclusions are drawn below:

- Accumulations of permanent deformations were higher at the OMC than 60% of DoS in all RAP mixed RCA samples. However, RCA exhibited well performance even at the OMC when the RAP portion was about 10.
- Five samples illustrated high resistance to plastically deform at 60% of DoS level. The results confirmed the presence of RAP up to about 15% in RCA specimens did not significantly affect on the accumulation of permanent strain. However, the accumulation of permanent axial strain increased with the increase of RAP portion in RCA.

- Corresponding moisture contents at 60% of DoS level of the samples exhibited best resilient moduli. Greater resilient modulus can be predicted with RAP up to 20% in RCA since the resilient modulus curves exhibited continuous increasing rate at the end of 50,000 load cycles. In contrast, resilient moduli were low at the OMCs. However, gaining of resilient moduli was steadily behaved within 50,000 of load cycles.
- Resilient modulus has varied within a small range with increasing the RAP from 0 to 20% in RCA at 60% of DoS which reflects insignificant impact on the resilient modulus when presence of RAP up to 20% in RCA.
- According to the analysed results of accumulation of permanent strain and resilient modulus, it can be concluded that presence of RAP in small quantities as a constituent in RCA does not significantly affect to degrade the quality and performance as unbound pavement material.

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