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Assessment of recycled concrete aggregates for road base and sub-base

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ABSTRACT

Population increase and economic developments can lead to construction as well as demolition of infrastructures such as buildings, bridges, roads, etc and used concrete is the main waste product of them. Recycling of waste concrete to obtain the recycled concrete aggregates (RCA) for base and/or sub-base materials in road construction is a foremost application to be promoted to gain economical and sustainable benefits. As the mortar, bricks, glass and asphalt present in different constituents in RCA, it exhibits inconsistent properties and performance. In this study, six different types of RCA samples were subjected classification tests such as particle size distribution, plasticity, compaction test and California Bearing Ratio (CBR). Results were compared with those of the standard road materials used in Queensland, Australia and found that 'RM1-100/RM3-0' and 'RM1-80/RM3-20' samples are sitting in the margin of the minimum required specifications of base materials while others are lower than that.

Keywords: Recycling, Waste concrete, Road materials

1. INTRODUCTION

Demolished materials are becoming more popular to recycle and reuse due to shortage of natural mineral resources, increasing waste disposal cost, and increasing the demand of materials. Conversely supplying the conventional aggregates for construction purposes make impact on resource depletion, environmental degradation, and energy consumption. Therefore reusing the recycled materials creates many economical and environmental benefits.

Crushed concrete can be considered and promoted as an alternative and a sustainable source of aggregate for construction industry. Successful studies have been revealed that recycled concrete aggregates can be applied as a partial or complete substitution of natural aggregates in the production of ordinary concrete [1], [2], [3]. However Hansen in 1992 [4] has proven that fine portion of RCA makes detrimental effects on the harden properties of concrete and the coarse RCA are the best use.

The studies on RCA as pavement materials are widely reported in last decades. Reference [5] shows the evaluation of the performance of RCA using as a base material under hot mix asphalts and as an aggregate in Portland cement concrete pavement while [6] reported that the performance of the subbase materials prepared with both course and fine RCA was comparable to that of conventional subbsase materials. Reference [7] introduced RCA as base and subbase material for supporting a concrete pavement while [8] concluded the feasibility of using RCA and crushed clay bricks as blended materials for un-bound granular subbases. Although these research findings have demonstrated the feasibility of using RCA as subbase material as well as for base course of the concrete pavements, a detailed investigation of RCA as base and subbase material for unbound pavements is required including classifications considering the variability of RCA compositions, performance characteristics under repeated loading, and evaluation of the performance of a granular pavement constructed using RCA and subjected to real traffic loading. As the first step of such a detailed investigation of RCA, this paper presents the results of classification tests of six different RCA samples to analyze the feasibility of using them in unbound granular pavement constructions comparing their classification properties with those of the conventional unbound granular materials used in Queensland.

2. MATERIALS USED

For this investigation, two main commercially available RCA products, namely RM001 and RM003, obtained from a leading concrete recycling plant in Queensland were utilized. Material sources are demolished building (slabs, floors, columns and foundations), bridge supports, airport runways and concrete road beds. The collected materials are undergone specified crushing process to produce RM 001 and RM 003. Table 1 shows the maximum percentages of the constituents that can be consisted in RM001 and RM003 at the plant output. These two materials were blended in different percentages by weight to form another four samples to represent various combinations of constituents. New sample types with their blending percentages are showing in Table 2.

Table 1: Percentage limits of constituents of two main RCAmaterials.

Recycled Material Type	Maximum Limit of each Constituent (Percentage by mass)		
	Reclaimed Concrete	*RAP	Brick
RM 001	100	-	-
RM 003	100	20	15

*RAP – Reclaimed Asphalt Pavement

Table 2. New RCA samples with blending percentages

Material name	Mixing percentages by mass (%)	
	RM001	RM003
RM1-100/RM3-0	100	0
RM1-80/RM3-20	80	20
RM1-60/RM3-40	60	40
RM1-40/RM3-60	40	60
RM1-20/RM3-80	20	80
RM1-0/RM3-100	0	100

3. LABORATORY TESTING, RESULTS AND DISCUSSION

Usually RCAs are highly heterogeneous and consist in different amounts of impurities and their quantities are not steady. This makes RCA to have inconsistent classification properties. Therefore it is essential to characterize the properties of RCAs through classification tests such as sieve analysis test, atterburg limits test, proctor compaction test and California bearing ratio (CBR) to investigate the possible range of variation of classification parameters. The results were compared with the specifications of base and subbase materials of Department of Main Roads in Queensland.

3.1 Grain Size Distribution

Particle size distribution of a particular pavement aggregate type affects its compressibility, permeability, density...etc [9] . Grain size distribution curves of all six testing RCA samples obtained from sieve analyses are shown in Fig 1. Further the maximum and minimum grading curves of material subtype 2.1 have been drawn in same figure. Material subtype 2.1 is applied for base layers by Department of Main Roads, Queensland and its gradation curves are drawn as their specifications. These demarcating lines are showing that fine content of the six samples are within required range but close to the minimum curve, while the course particles have exceeded the maximum gradation curve at the top. But all the curves show that a greater fraction of their curves are laid within the specified range.

According to the unified soil classification system (USCS), except ‘RM1-0/RM3-100’, other five samples are categorized as ‘well graded gravel’. The ‘RM1-0/RM3-100’ present approximately half of sand and half of gravel with slightly susceptible to gravel.

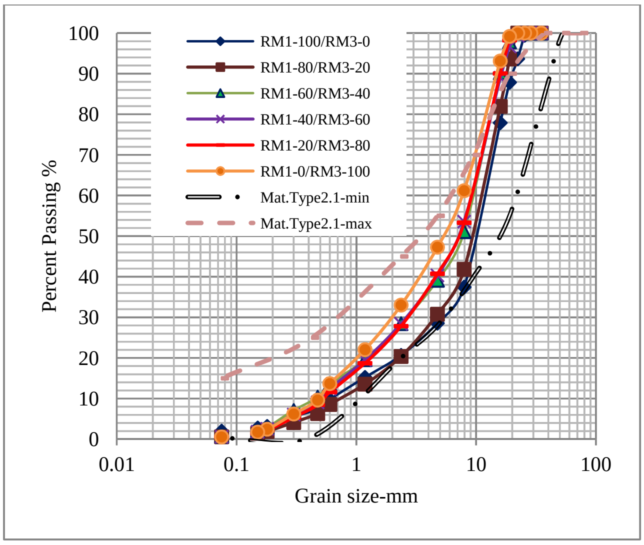

Fig 1. Gradation curves for six samples and maximum & minimum curves of subtype 2.1 materials

Table 3. Plasticity Index of two main materials

Fine Sample	RM1-100/RM3-0	RM1-0/RM3-100
LL	21	27
PL	15.6	20
PI	5.4	7

3.2 Plasticity

Cone-penetrometer method was followed to deter-mine the liquid limit (LL) as well as plastic limit test was done for plastic limit (PL) for the sample of fines passing 0.475 mm sieve. Fines of only ‘RM1-100/RM3-0’ and ‘RM1-0/RM3-100’ were tested since other four samples are blended of these two. The LL values and mean values of plastic limit (PL) test (Atterberg limit test) were summarized in Table 3. According to the Department of Main Roads specifications the maximum plasticity index (PI) is 6 for material subtype 2.1(See section 3.1). ‘RM1-100/RM3-0’ is within that range but ‘RM1-0/RM3-100’having PI of material subtype 2.3 which is given maximum PI as 8. The subtype 2.3 is applied for upper subbase layers by Main Roads.

3.3 Compaction

The moisture density curve (compaction curve) of a soil is an indicator of the sensitivity of the density with respect to the variation of moisture content in the materials [10]. Materials with flat curves can tolerate a greater amount of variations in the moisture content without compromising much of the achieved density from compaction. In contrast, materials with sharp curves are extremely sensitive to the optimum value during compaction.

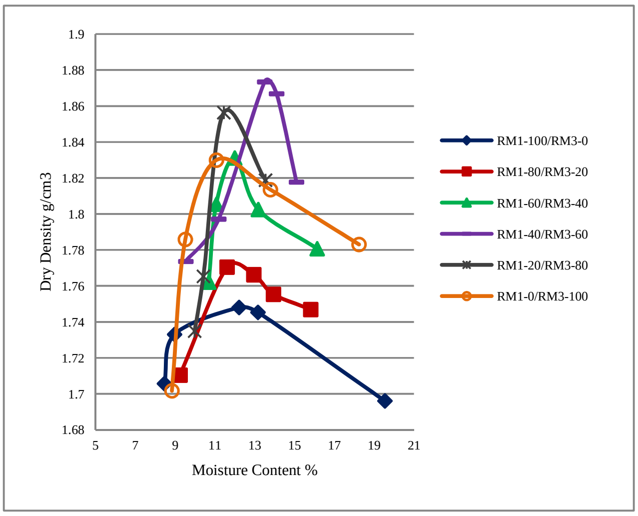

Fig 2. Compaction curves for Six Samples

Table 4. Optimum Moisture Content and Maximum Dry Density for Six Samples

Sample Type	Optimum Moisture Content %	Maximum Dry density (g/cm^3)
RM1-100/RM3-0	13.2	1.748
RM1-80/RM3-20	13.2	1.768
RM1-60/RM3-40	13.3	1.822
RM1-40/RM3-60	13.5	1.856
RM1-20/RM3-80	14.0	1.836
RM1-0/RM3-100	14.2	1.846

Standard proctor compaction test in accordance with Australian Standards [11] was performed on each testing sample and the results are shown in Fig 2. Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) values of each material obtained from Fig. 2 are tabulated in Table 4. The range of the variation of MDD and OMC are relatively small as 1.748-1.846 g/cm3 and 13.2-14.2%, respectively. It can be seen that with the increase in fines contents of a material, both OMC and MDD increase as fines can absorb more water and can reduce the void volume by filling the voids between larger particles.

Furthermore, with the increase in fine in the samples the curves are more pointed showing the sensitivity of mixture of water. And it is also interesting to note that all the samples are more sensitive to the moisture variation on the dry side of the OMC curves than the wet side of the OMC.

Table 5. Variation of CBR values with different moisture homogenization periods

	CBR %		
Sample Type	No moisture homogeni zation period	3 hrs moisture homogeniz ation period	*8 hrs moisture homogeni zation period
RM1-100/RM3-0	61	74	55
RM1-80/RM3-20	56	63	-
RM1-60/RM3-40	55	66	-
RM1-40/RM3-60	50	61	-
RM1-20/RM3-80	48	60	-
RM1-0/RM3-100	46	50	53

*CBR was conducted only for two samples to observe the strength gaining pattern

3.4 CBR tests

CBR characterization is widely used in pavement industry to provide a relative measure of strength, elastic modulus and moisture durability across various road materials for structural design purposes [9]. CBR tests were performed as specified in AS 1289.6.1.1 – 1998 [12]on the six samples compacted at their corresponding OMCs.

In order to find out the optimum moisture homogenization period (time between material mixing with water and compaction), a series of CBR tests were performed on RCA samples prepared allowing different moisture homogenization periods (e.g. 0, 3, 8 hours) since the main components of crushed concrete; aggregates, cement motar, sand need specific time period for uniformly moisture distribution. The results of these CBR tests are tabulated in Table 5.

The samples under 'No moisture homogenization period' have given the lowest CBR values since they did not have enough time for homogenization of moisture and therefore lower the compaction and CBR values. 3 hours curing period showed higher CBR values since the materials have taken sufficient time for uniformly moisture distribution which helps for properly compaction of the samples. But RM1-100/RM3-0 showed lower CBR values for 8 hours curing period while RM1-0/RM3-100 had its highest CBR value than previous conditions. RM1-0/RM3-100 consists on more fines, clay bricks, and RAP particles which need more time and 3 hours insufficient for uniformly moisture distribution. In the RM1-100/RM3-0 neither clay bricks nor

RAP, but when higher the curing time (8 hours) the cement motar separately harden themselves and the inter particle connection between those the harden cement motar and recycled aggregates caused poor compaction as well as poor load transfer through materials under loading. Therefore 3 hours moisture homogenization was followed for the next CBR test series.

3.4.1CBR test for unsoaked samples

Next CBR test series were conducted to investigate the effects of unsoaked curing periods of the compacted samples on CBR values. Each sample was prepared following the 3 hours curing period and followed standard compaction procedure. The sample compacted into the mould was cured (unsoaked) in a sealed container for different periods (e.g. 4 and 8 days) with 4.5kg surcharged load before testing. The variations of CBR values with curing periods for each RCA are shown in Table 6. 4 days curing for compacted samples were followed since it is followed for standard aggregates by the Department of Main Roads. 8 days curing period for compacted samples were applied to observe the strength gaining with time. RM1-100/RM3-0 and RM1-80/RM3-20 had slightly lower values of their CBR after 8 days curing of the compacted samples. The fine particles of these compacted samples were settled themselves under 4.5 kg surcharge load for 8 days. This caused to form little voids between irregular shapes recycled aggregates since these two sample types have very low amount of fines comparatively other samples. This makes weak inter connection in the upper part of the compacted sample while load transferring and caused for low CBR values.

Table 6. CBR Values for Different Curing Period of Compacted Samples

	CBR %	
Sample Type	Mixture-3 hrs curing & compacted sample cured 4days	Mixture-3 hrs curing & compacted sample cured 8days
RM1-100/RM3-0	81	78
RM1-80/RM3-20	77	75
RM1-60/RM3-40	74	75
RM1-40/RM3-60	63	64
RM1-20/RM3-80	60	60
RM1-0/RM3-100	58	41

RM1-60/RM3-40, RM1-40/RM3-60, RM1-20/RM3-80 had almost same but slightly higher CBR values respectively. Higher compactability due to the high fine fraction and high water absorption for cement motar strength gaining affect their greater load bearing strength.

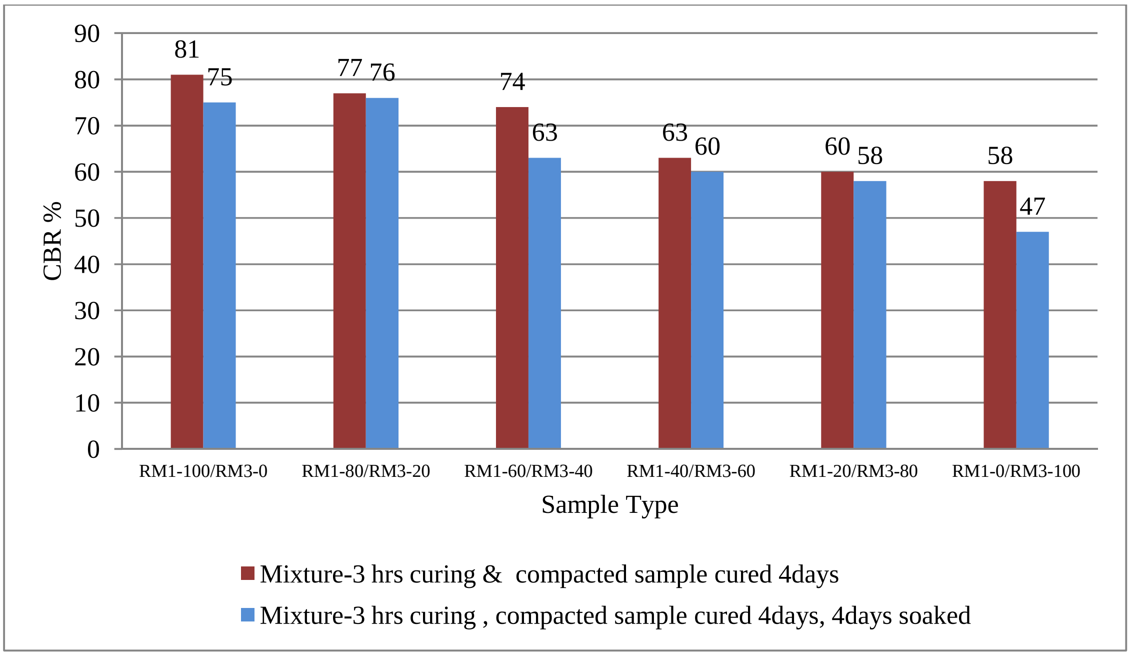

Fig 3. Summary of CBR values for best unsoked and soaked results

RM1-0/RM3-100 had its lowest CBR values and this is due to the lower intrinsic particle strength of crushed bricks and reclaimed asphalts (RAP) which led to lower overall bearing strength of RCA [13]. Also the poor interlocking system due to the crushed clay brick and sand decrease the load transfer capacity of the compacted samples.

3.4.2 CBR test for soaked samples

Testing the CBR values of pavement materials after soaking is more significant to observe the strength of materials under fully saturated condition. This is highly applicable for flood risk areas in material selecting and pavement designing. The Department of Main Roads in Queensland has introduced minimum required soaked CBR value as 80 for base layers. The soaked CBR results and the best CBR values which were shown by the mixture cured 3 hours and compacted samples cured 4 days are shown in Fig 3. For the soaked test, materials were cured 3 hours prior to compaction and the compacted samples also cured for 4 days with 4.5kg surcharged load prior to testing. It shows that soaked CBR values are slightly less than the unsoaked values which has the same curing times but not reached the minimum requirement of the Main Road's specifications.

4 CONCLUSION

- RCAs have fewer fines but higher percentage of coarse fraction. The six curves are shown minimum required particles size distribution of material subtype 2.1.
- The proctor compaction test gave relatively higher water absorption for maximum dry density. Cement, rock dust and clay bricks cause for higher compaction with increase the RM 003 portion but lower the density. However the density varied in a small range giving the lowest value for 'RM1-100/RM3-0' which represents only crushed concrete aggregate.
- 'RM1-100/RM3-0'sample has certainly very appreciable results at CBR test at the both soaked and unsoaked. 'RM1-80/RM3-20'sample also has come close to 'RM1-100/RM3-0' with CBR results but lesser values. However, this improvement is laid in the margin of the minimum requirement of the pavement aggregates' CBR values which employ for base layer (CBR 80 for soaked condition, [14]) as introduced by Main Roads in Queensland. But it is possible to conclude that six sample types are showing appropriate strength for employing as a subbase aggregate as well as being able to be reusing in base for low or average traffic pavements.

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