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# Sustainable Application of Recycled Glass Blended with Crushed Rock

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## ABSTRACT

Current levels of natural aggregate production are under threat due to fast diminishing resources for virgin aggregates. Under this circumstance, waste materials may be recycled to be used as an alternative material in pavement as base/subbase material. Hence, there is now a developing emphasis on environmental management which has resulted in growing pressure to investigate the viability of reusing of all categories of waste materials. Recycled glass is a waste material produced in large quantities in municipal and industrial areas in Australia and worldwide. Currently in the state of Victoria, Australia, 186,000 tonnes of recycled glass is stockpiled annually and this figure is growing every year. To date, there is little known reuse of recycled glass in pavement subbase applications due to limited knowledge concerning its geotechnical properties. The reuse of recycled glass in road pavement applications will provide the opportunity not only to eliminate the waste glass stockpiles and minimize the use of virgin materials in pavement applications but also to minimize the valuable land being used for landfilling. This paper discusses the properties of recycled glass when used in blends of up to 50% with crushed rock in pavement subbase applications. Laboratory geotechnical tests discussed in this paper include modified compaction, Los Angeles abrasion loss, triaxial compression tests and California Bearing Ratio (CBR) tests. The findings of this research indicate that initially up to 30% recycled glass with the maximum particle size of 4.75 mm could be safely added to crushed rock when used in pavement subbase applications.

*Keywords: recycled glass, waste materials, crushed rock, pavement subbase, CBR, triaxial tests*

## 1 INTRODUCTION

Waste materials have been defined as any type of material by-product of human and industrial activity that has no lasting value (Tam and Tam 2006). The growing quantities and types of waste materials, shortage of landfill space and lack of natural earth materials highlight the urgency of finding innovative ways for the recycling and reusing of waste materials (Ali et al. 2011). In Victoria, Australia the total amount of the recovered waste material is recorded as 6.56 million tonnes during the financial year 2008-2009 and around 64% of the solid wastes were recycled over that period (Sustainability Victoria 2009). 82% of the material received for reprocessing during the 2008–2009 was sourced from the combined industry sectors, i.e. commercial and industrial and construction and demolition (C&D) industries, with C&D material accounts for 47% of all material (by weight) recovered (Sustainability Victoria 2009). Among C&D material, concrete was the major component representing 55% (by weight) of the total followed by rock/excavation stone (21%), brick/brick rubble (8%), soil/sand (5%), asphalt (7%), mixed C&D waste (3%) and plasterboard (1%) (Sustainability Victoria 2009). Recycling of C&D materials would clearly provide substantial benefits to the industry in terms of reduced material supply and waste disposal cost, increased sustainability and reduced environmental impact (Ali and Arulrajah 2012, Arulrajah et al. 2011a; b, Sivakumar et al. 2004).

This paper primarily focuses on the sustainable application of recycled glass with crushed rock in road pavement subbase applications. The engineering properties of recycled glass blended with crushed rock were investigated and compared with the specifications outlined by the local road authority (VicRoads) for road pavement subbase applications.

The Recycled Glass (RG) and Crushed Rock (CR) mixtures were prepared in a range of proportions. Particle size distribution, specific gravity, water absorption, organic content, pH value, modified proctor compaction tests, Los Angeles (LA) Abrasion loss, consolidated drained triaxial tests and California Bearing Ratio (CBR) tests were undertaken on all mixtures.

## 2 SAMPLING LOCATIONS AND SOURCES

Samples of Class 3 CR (20 mm nominal size) originated from basalt floaters or surface excavation rock and RG (4.75 mm minus) derived from household waste collection as well as C&D activities were collected from the Alex Fraser Group recycling site in Victoria, located approximately 20 km to the west of Melbourne, Australia. Following standard procedures, representative samples were placed in plastic bags and tightly sealed to retain the natural moisture content and then transported to Geomechanics laboratory at Swinburne University of Technology.

## 3 LABORATORY TESTING PROGRAMS

In order to investigate the sustainable application of RG blended with CR in road pavement subbase applications without compromising its physical, mechanical and environmental criterion, a series of laboratory tests were undertaken. The tests included were modified compaction, grain size distribution, specific gravity, hydraulic conductivity, flakiness index, Los Angeles abrasion loss, consolidated drained (CD) triaxial compression, pH value, organic content and California Bearing Ratio (CBR).

## 4 EXISTING SPECIFICATIONS IN VICTORIA

VicRoads classifies recycled crushed aggregates into four classes for use in pavements namely Class 1, Class 2, Class 3 and Class 4 (VicRoads 2009). This classification is based on the physical and mechanical properties of recycled crushed aggregates. Class 1 and Class 2 crushed aggregates are usually specified for base-course applications, while Class 3 and Class 4 are restricted primarily to upper subbase and lower subbase applications, respectively (VicRoads 2009). The physical properties of crushed aggregates specified by VicRoads can be found in Ali et al. 2011.

## 5 LABORATORY STUDY ON RG/CR BLENDS

In this research, RG blended with CR is denoted by RGXX/CRYY. The suffix XX after RG represents the percentage of RG and the suffix YY after CR represents the percentage of CR in the mixture by mass, respectively. The laboratory study on RG/CR blends was conducted on mixtures comprised of 10%, 15%, 20%, 30%, 40% and 50% RG mixed with Class 3 CR. The tests were also conducted on 100%RG and 100%CR for comparison and are regarded as RG100 and CR100, respectively.

The results of geotechnical engineering tests conducted on RG/CR blends are presented in Table 1. According to the Unified Soil Classification System (USCS) (ASTM D 2487-11), RG can be classified as SW, while RG/CR blends can be classified as SP-SM as shown in Table 1.

As shown in Table 1, the specific gravity of blends is increasing with the increase in the percentages of CR content of the mixtures. This is due to higher specific gravity of CR compared to RG. Table 1 also suggests that RG possesses a specific gravity value of 2.49 which is approximately 10% lower than that of natural aggregates varying between 2.60 and 2.83, while the value for CR is the same as those of natural aggregates (CWC 1998, Ali et al. 2011). The results of water absorptions values indicate that RG has a lower water absorption value than those of the CR and RG/CR blends as expected. This is believed to be the result of the nature of the material and the impermeable smooth surfaces of RG particles as compared to CR and RG/CR blends (Ali et al. 2011).

The organic content in the blends varies between 0.5% and 0.8% indicating stable behaviour of the material. All the blends have low percentage of fine particles varying from 2.8% to 12.0%. The fines contents of the blends are increasing with increase in CR content. The majority of this fine content is believed to be of silt size particles as indicated by non-plastic nature of the blends. Atterberg limit tests conducted on all blends showed that the blends are non-plastic. The primary reason for this is the fact that the Atterberg limits depend on the predominant mineral in the soil (Budhu 2007) and as such, very low fines content with silty materials results in immeasurable plasticity. This aspect suggest that some difficulties may be experienced with the workability of the RG blends as cohesion of particles and a “tight” prepared surface are usually sought after characteristics. A field trial of the RG/CR blends would best determine the level of difficulties that may be experienced. An addition of small quantities of clayey sand or plastic crushed fines may also be a good solution to overcome this potential problem.

*Table 1: Geotechnical properties of RG/CR blends*

| Test Description | | RG100 | RG50/ CR50 | RG40/ CR60 | RG30/ CR70 | RG20/ CR80 | RG15/ CR85 | RG10/ CR90 | CR100 |
|---|---|---|---|---|---|---|---|---|---|
| USCS classification | | SW | SP-SM | SP-SM | SP-SM | SP-SM | SP-SM | SP-SM | SP-SM |
| Specific Gravity ($G_s$) | | 2.49 | 2.64 | 2.68 | 2.73 | 2.78 | 2.76 | 2.79 | 2.84 |
| Water absorption (%) | | 1.00 | 2.00 | 2.10 | 2.53 | 2.27 | 2.62 | 2.58 | 2.56 |
| Organic content (%) | | 0.5 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.8 | 0.8 |
| pH | | 9.6 | 9.6 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 | 9.4 |
| LA Abrasion value | | 27 | 25 | 25 | 24 | 24 | 23 | 24 | 24 |
| Modified proctor | $\gamma_d$ (kN/m$^3$) | 18.0 | 20.9 | 21.0 | 21.4 | 21.7 | 22.0 | 22.2 | 22.6 |
| | $w_{opt}$ (%) | 9.2 | 8.8 | 9.0 | 9.3 | 9.2 | 8.5 | 8.1 | 8.7 |
| CBR (%) | | 44 | 121 | 137 | 152 | 165 | 199 | 170 | 181 |
| Permeability (m/s) | | 3.5E-5 | 7.1E-8 | 6.0E-8 | 6.0E-8 | 9.4E-8 | 6.8E-8 | 6.7E-8 | 6.1E-8 |
| Flakiness index | | NA* | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| Fine content (%) | | 2.8 | 8.1 | 8.8 | 9.2 | 9.9 | 10.9 | 10.5 | 12.0 |
| CD Triaxial Test | | | | | | | | | |
| Cohesion (kPa) | | 5 | 31.0 | 45.9 | 42.6 | 42.6 | 59.3 | 32.8 | 69.6 |
| Internal friction angle (°) | | 41.7 | 46.7 | 46.5 | 47.4 | 49.3 | 47.2 | 50.3 | 48.0 |

*Not Applicable

Flakiness index is an important parameter for pavement structures as flaky particles may reduce the workability (Tam and Tam 2007). A suggested value of flakiness index of 40 could be used as the upper limit for aggregates in a pavement base application (Tam and Tam 2007). The flakiness indexes of all the blends are well below the limit of 40 suggesting an acceptable limit.

As shown in Table 1, the pH value of the RG/CR blends vary from 9.4 to 9.7. According to the federal regulatory limit, a solid material is designated as hazardous waste when it contains a pH less than or equal to 2.0 or greater than or equal to 12.5 (CWC 1998). As such the pH values of the RG/CR blends are outside the limit designated as hazardous. However, a thorough leachate analysis is essential to make sure that the leachate will not impose any risk to the water streams and water bodies and this is out of the scope of this paper. More details of the leachate analysis of RG can be found on Disfani et al. 2012.

The optimum moisture contents and their corresponding maximum dry densities are also shown in Table 1. From Table 1, it is evident that with increasing the RG content in the mixtures, the maximum dry density (MDD) decreases. The maximum dry densities obtained for RG samples are approximately 10% lower than the values of 19-20 kN/m$^3$ found for natural aggregate with the same soil classification (Craig 1997). The maximum dry density increases with the increase in CR content as expected.

LA abrasion value is a useful indicator of the durability and hardness of aggregates during crushing and compaction and is commonly used in highway and materials engineering to assess the abrasion resistance of aggregate materials (Wartman et al. 2004). The RG/CR blends had wear values in the range of 23 to 27% as shown in Table 1. Natural aggregates typically have wear values in the range of 10% to 35% (PennDOT 2001), and VicRoads (2009) specifies the maximum limit of LA as 35% for Class 3 subbase materials. Therefore, the LA abrasion values of RG/CR blends are well within this typical range.

The CBR value is a common bearing capacity test used in the design of flexible pavement. Typical CBR values of a compacted granular material vary from 40 to 80 (NYDOT 1995). The CBR value of the RG/CR blends vary from 121 to 199% as shown in Table 1. The CBR values of all the RG/CR blends were higher than the minimum CBR value of 80% specified by VicRoads. Therefore, it can be concluded that the RG/CR blends will perform much better than the Class 3 materials in pavements.

Hydraulic conductivity determined from constant head method for the RG is considered to be of high permeability similar to sand, which is as expected. Hydraulic conductivity of RG/CR blends and CR100 determined by falling head method can be described as low. The hydraulic conductivity values of the

RG/CR blends are similar to the reported value of $6.59 \times 10^{-8}$ m/s for a natural aggregate (Poon and Chan 2006).

Consolidated drained (CD) triaxial compression tests were undertaken on 100%RG, 100%CR specimens as well as on RG/CR blends according to ASTM D 4767-04 with a strain rate of 0.01%/min. The diameter and height were 50 mm and 100 mm, respectively of the RG specimens and 100 mm and 200 mm, respectively for CR and RG/CR specimens. The internal friction angle of RG/CR blends varies from 46.5° to 50.3° and the cohesion ranges between 31.0 kPa and 69.6 kPa. Generally, all blends attain high shear strength parameters. Although the RG100, CR100 and RG/CR blends are considered as cohesionless material, it deviated from purely frictional behaviour. Figure 1 presents the deviator stress versus axial strain diagram for RG40/CR60 blend. It was noted that the deviator stress increases with vertical strain until it reaches the peak strength. It was also noticed that at higher confining pressures, the peak strength becomes higher and the vertical strain corresponding to the peak strength also becomes higher. All three curves reveal that after the peak strength, the deviator stress decreases with vertical strain. This characteristic is normally described as strain softening which would be a good characteristic for road subbase and base material. The minor cohesion value for RG as shown in Table 1 might be due to particle adhesion resulting from label glues, residual sugars or other cohesive substances present in the samples (Ali and Arulrajah 2012, Wartman et al. 2004). The volumetric strain versus axial strain diagram for RG40/CR60 blend is presented in Figure 2. The positive volumetric strain indicates the contractive behaviour and the negative volumetric strain indicates the dilative behaviour of the samples. All the samples show similar volumetric strain characteristics. The samples compressed in the initial stage of the shearing and then started to dilate. Generally, the dilation of samples during shearing increases with increased axial strain. It can be also seen that the higher the confining stresses, lower the volumetric strain at the same axial strain. The volumetric strain characteristics of the specimens are similar to the dense cohesionless soil subjected to similar test conditions. The Mohr-Coulomb failure envelope for that blend is shown in Figure 3.

## 6 CONCLUSION

The laboratory studies carried out in this research work have shown overall that the incorporation of up to 50% RG has low to minimal effect on the physical and mechanical properties of the original material (CR). As such, the RG/CR blends were found to satisfactorily meet the current VicRoads requirements. The research indicates that initially up to 30% “4.75 mm minus” RG could be safely added to Class 3 CR. Depending on the results of future field trials, it may be possible to increase the percentage of RG in the mixture. All RG/CR blends tested for CBR and LA abrasion showed satisfactory results according to VicRoads requirements for Class 3 pavement subbase material. The RG/CR blends showed good shear strength in CD triaxial compression tests.

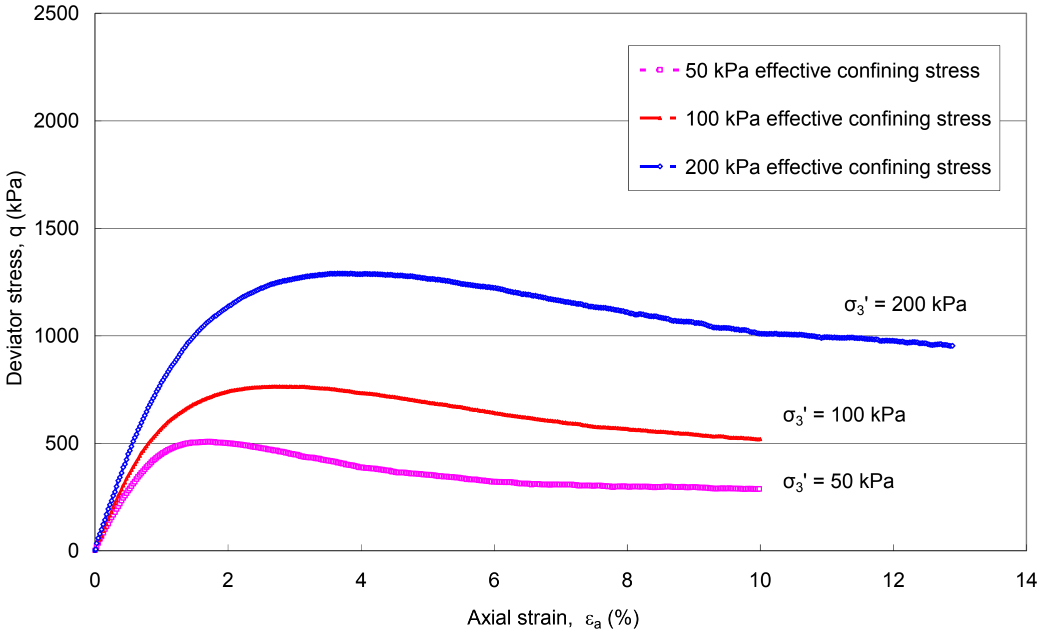

*Figure 1. Deviator stress versus axial strain relationship for RG40/CR60*

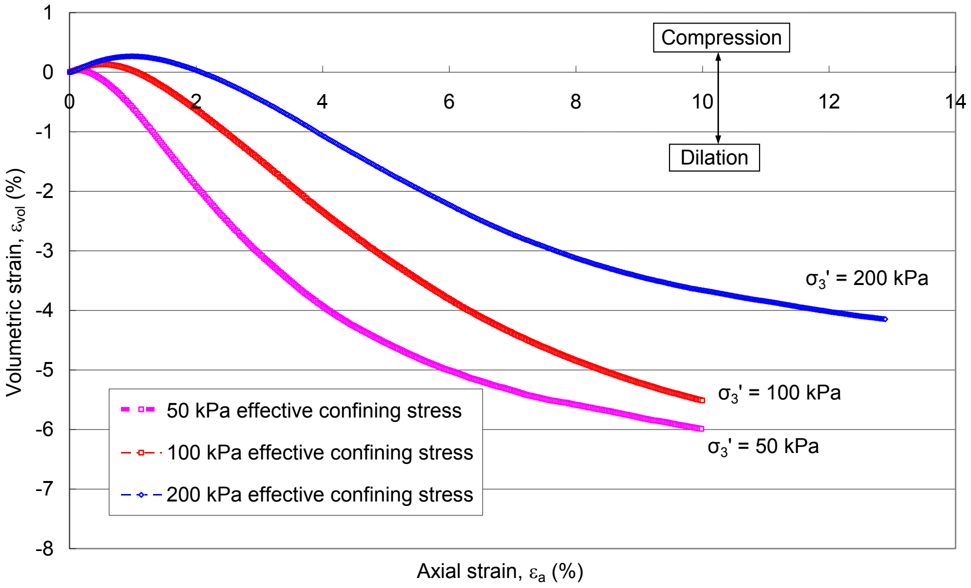

*Figure 2. Volumetric strain versus axial strain relationship for RG40/CR60*

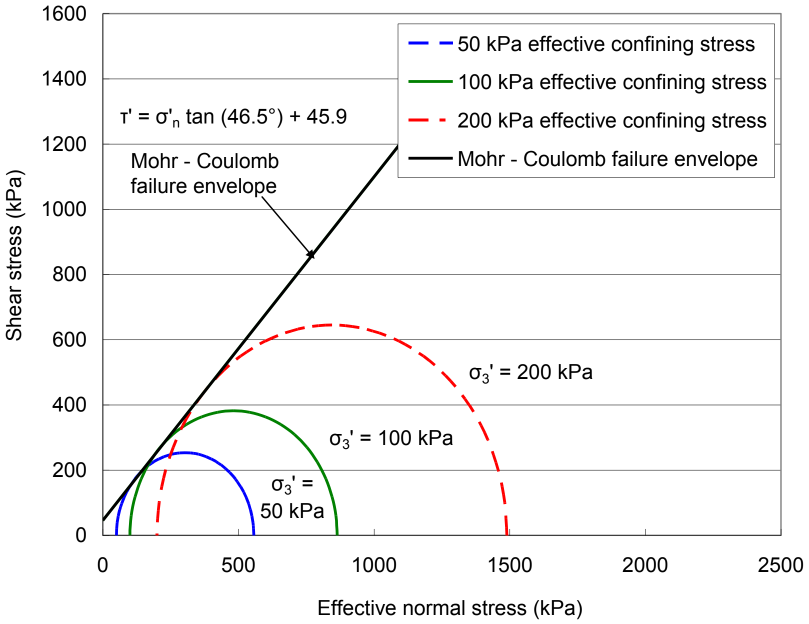

*Figure 3. Mohr's circles and Mohr- Coulomb failure envelope for RG40/CR60*

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