# Geotechnical characteristics of recycled glass-biosolid mixtures

## Les Caractéristiques géotechniques des mélanges de verre-biosolid recyclé

M. M. Disfani, A. Arulrajah & V. Suthagaran
*Swinburne University of Technology, Melbourne, Australia*
M. W. Bo
*DST Consulting Engineers Inc., Canada*

ABSTRACT

The sustainable reuse of waste materials such as recycled glass (RG) and biosolids (Bio) in geotechnical applications would greatly reduce the demand for landfill sites and for virgin materials. The most important obstacle in the sustainable use of recycled glass and biosolids mixtures in geotechnical applications is the lack of knowledge about their engineering characteristics particularly when they are blended together. The use of such mixtures is a cost effective and innovative way of reusing both waste materials and overcoming the deficiencies that they would possess if they were used on their own. Preliminary tests were conducted on samples made of purely recycled glass and biosolids and also on blended RG-Bio samples to determine their geotechnical parameters. Particle size distribution, compaction tests and Direct Shear Tests (DST) were undertaken on both pure and blended materials. The shear strength characteristic of the mixture and its relation to the percentage of each component were analysed. It was concluded that the mixture takes advantage of the friction resistance of coarser recycled glass particles and the cohesion strength of finer particles which are mostly from biosolid grains. The results indicated that the RG-Bio mixtures have satisfactory shear strength characteristics which enable these mixtures to have an excellent potential to be used as an embankment fill material in roads.

RÉSUMÉ

L'utilisation renouvelable des matériaux déchets tels que le verre recyclé (VR) et les biosolides (Bio) dans des applications géotechniques redus considérablement la demande pour des sites d'enfouissement des déchets et des matériaux vierges. L'obstacle le plus important dans l'utilisation renouvelable du verre recyclé et des mélanges biosolides dans l'application géotechnique est le manque de connaissance sur les caractéristiques de l'ingénierie en particulier quand ils sont mélangé pour former un nouveau mélange de verre-biosolides recyclé est un façon retable et novateur de réutilise ces matériaux déchets et de surmonter les carences que chacun d'entre eux indiquent si ils ont été utilisés singulièrement. Des testes préliminaires ont été effectués sur des échantillons qui constitue purement de verre recyclé ou des biosolides et de surcroît sur des échantillons d'un mélange de VR-Bio avec des différents rapports pour déterminer leur paramètres géotechniques. Distribution granulométrique des particules, compact tests, et essai de cisaillement direct ont été menés sur les deux matériaux purs et mélanges. Le comportement du cisaillement du mélange et sa relation avec le pourcentage de chaque élément ont été analysés. Il a été conclu que le mélange prend avantage de la résistance de frottement des particules grossières de verre recyclé et de la force de cohésion de fines particules qui sont pour le plupart des grains biosolides. Les résultats indiquent que les mélanges de RV-Bio ont satisfis la cisaillement comportement qui leur donne un énorme potentiel d'être utilisé comme remblai pour les talus dans les applications des travaux routiers

Keywords : recycled glass, biosolids, waste materials, geotechnical properties

## 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 & Tam 2006). The escalating quantities and type of waste materials, shortage of landfill spaces and lack of virgin materials imposes pressure on urgency of finding innovative ways of recycling and reusing waste materials. The recycling and subsequent reuse of waste materials will also reduce the demand for virgin natural resources which consequently leads to less energy usage, lower green gas emissions and ultimately a more sustainable environment.

Recycled Glass (RG) is a mixture of different colored glass particles and often comprises a wide range of debris (mainly paper, plastic, food remaining and metals). The presence of different colored glass and diverse types of debris are the primary obstacles in reusing recycled glass in bottle production industries. Recycled glass passing 9.5 mm sieve does not have the primary shape of the original container and to some extent resembles natural and quarried aggregates (Wartman et al. 2004). Various research has been carried out to study the feasibility of using recycled glass in various geotechnical engineering applications. This includes using recycled glass as asphalt aggregate, as backfill material, in embankments, as drainage material, as filter media and in road pavements. The main consideration with regards to the shear strength of recycled glass is lack of cohesion between particles. This is mainly the result of smooth surfaces of crushed glass particles and lack of fine clay size particles in the mixture.

Currently experimental works undertaken at Swinburne University of Technology, Australia indicates that crushed recycled glass passing the 4.75 mm sieve comprises of well graded sand size material mixed with low percentage of silt size material according to USCS. Three different sources of recycled glass with maximum particle size of 19 mm, 9.5 mm and 4.75 mm were considered in this research. These three sources were respectively categorized in term of grain size as GP, SW-SM and SW-SM according to the USCS soil classification system. The main difference between theses three sources was the maximum size which consequently affects the particle size distribution. The differences in particle size distribution affect other geotechnical properties including hydraulic conductivity, compaction characteristics and shear strength parameters. Due to high segregation potential, high percentage of flat and elongated shaped particles, weak shear resistance and low capability of absorbing and holding water (which affects the

*Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering*
*M. Hamza et al. (Eds.)*

*doi:10.3233/978-1-60750-031-5-201*

compaction behaviour of material) the 19 mm (GP) glass cullet was found to be inappropriate for geotechnical applications. Among recycled glass finer than 9.5 mm (SW-SM) and finer than 4.75 mm (SW-SM), the recycled glass finer than 4.75 mm shows better shear strength characteristic. This is mainly because of lower debris level and fewer flat and elongated particles. Due to these factors, it was decided that glass cullet with a maximum particle size of 4.75 mm was the optimum material for this research project.

Biosolids (Bio) are treated sewage sludge suitable for beneficial use in accordance with the relevant regulations. The characteristics of the biosolids depend on various factors such as the type of waste, type of treatment process and age of the biosolids. Geotechnical engineering properties of the untreated biosolids were determined from laboratory tests. The experimental results indicated that untreated biosolids lack enough shear resistance and friction between particles.

To overcome the deficiencies of recycled glass and biosolids when used on their own and to enhance the strength properties of them the innovative idea of mixing these two materials was studied. The blended mixture has the advantage of combining the high friction properties of recycled glass with the cohesion characteristic of biosolids to achieve a reasonable shear strength level. The recycled glass and biosolids (RG-Bio) mixtures were prepared in various proportions. Geotechnical tests including particle size distribution, standard and modified compaction tests and direct shear tests were conducted on all mixtures.

## 2 LABORATORY STUDY ON RECYCLED GLASS

Recycled glass finer than 4.75 mm, provided by Alex Fraser Group, Melbourne, was used in the research. Table 1 shows the geotechnical parameters of pure recycled glass samples. Values presented are averages of several tests on different samples.

Table 1. Geotechnical properties of pure recycled glass

| Test | Standard | Results |
|---|---|---|
| Australian soil classification | AS 1726-1993 | SW-SM |
| USCS classification | ASTM D2487-98 | SW-SM |
| Coefficient of uniformity ($C_u$) | AS 1726-1993 | 7.6 |
| Coefficient of curvature ($C_c$) | AS 1726-1993 | 1.3 |
| Gravel content (2.36 mm >) (%) | AS 1726-1993 | 8.9 |
| Sand content (0.075 – 2.36 mm) (%) | AS 1726-1993 | 85.6 |
| Fine content (< 0.075 mm) (%) | AS 1726-1993 | 5.5 |
| Specific gravity ($G_s$) | AS 1289.3.5.1 | 2.48 |
| Organic content (%) | ASTM D 2947-00 | 1.3 |
| Debris level (visual method) (%) | AGI [1]23.1 & 23.2 | 7 |
| Debris level (weight method) (%) | CWC[2] chart | 1.23 |
| $\gamma_{d\,max}$ (kN/m$^3$) - standard proctor | AS 1289.5.1.1 | 16.7 |
| $w_{opt}$ (%) - standard proctor | AS 1289.5.1.1 | 11.2 |
| $\gamma_{d\,max}$ (kN/m$^3$) - modified proctor | AS 1289.5.2.1 | 17.5 |
| $w_{opt}$ (%) - modified proctor | AS 1289.5.2.1 | 10 |
| Hydraulic conductivity (m/s) | BS 1377-5 | 1.7 E -5 |
| pH value | AS 1289.4.3.1 | 9.87 |
| Internal friction angle (degree)- Direct Shear Test ($\sigma_n$: 30-120 kPa) | BS 1377-7 | 45-47° |
| Internal friction angle (degree)- Direct Shear Test ($\sigma_n$: 60-240 kPa) | BS 1377-7 | 42-43° |
| Internal friction angle (degree)- Direct Shear Test ($\sigma_n$: 120-480 kPa) | BS 1377-7 | 40-41° |
| California Bearing Ratio (CBR) | AS 1289.6.1.1 | 45-50 |

1- American Geological Institute
2- Clean Washington Centre

Test results indicate that the fine recycled glass (SW-SM according to USCS) has a specific gravity about 15% less than natural aggregate. The debris level obtained in weight method is less than one fifth of the value obtained by visual method. The primary reason for this is the fact that a high percentage of the debris is low density material that includes paper and plastic. The moisture content and density relationship curve for glass cullet is similar to characteristic convex shape of natural aggregates (Wartman et al. 2004). The low sensitivity of recycled glass to moisture content changes in comparison to natural aggregate is evident from the flatter compaction curves. This characteristic gives recycled glass stable compaction and good workability over a wide range of water contents in geotechnical engineering applications (Wartman et al. 2004). Recycled glass is vulnerable to crushing to smaller size particles under compaction impacts. It was observed that particle size distribution of recycled glass changed to a finer material after compaction. This effect was noted to be negligible after standard compaction effort and noticeable after modified compaction effort. The hydraulic conductivity of recycled glass is classified as medium according to permeability classifications (Terzaghi et al. 1996) which is similar to natural aggregates. The internal friction angle of recycled glass is similar to that of dense sand with angular grains (Das 2008). The internal friction angle decreases with an increase in the normal stress level.

## 3 LABORATORY STUDY ON BIOSOLIDS

Geotechnical laboratory tests were performed on three different samples collected from biosolid stockpiles at the Western Treatment Plant in Victoria, Australia. Table 2 presents a summary of test results of untreated biosolids samples.

Table 2. Geotechnical properties of pure biosolids

| Test | Standard | Results |
|---|---|---|
| Australian soil classification | AS 1726-1993 | OH |
| USCS classification | ASTM D2487-98 | OH |
| Coefficient of uniformity ($C_u$) | AS 1726-1993 | 26 |
| Coefficient of curvature ($C_c$) | AS 1726-1993 | 0.3 |
| Gravel content (2.36 mm >) (%) | AS 1726-1993 | 4 |
| Sand content (0.075 – 2.36 mm) (%) | AS 1726-1993 | 54.6 |
| Fine content (< 0.075 mm) (%) | AS 1726-1993 | 41.4 |
| Liquid limit (%) | AS 1289.3.1.1 | 104 |
| Plastic limit (%) | AS 1289.3.2.1 | 80 |
| Plasticity index | AS 1289.3.3.1 | 24 |
| Specific gravity ($G_s$) | AS 1289.3.5.1 | 1.8 |
| Organic content (%) | ASTM D 2947-00 | 25.9 |
| $\gamma_{d\,max}$ (kN/m$^3$) - standard proctor | AS 1289.5.1.1 | 8.1 |
| $w_{opt}$ (%) - standard proctor | AS 1289.5.1.1 | 53 |
| $\gamma_{d\,max}$ (kN/m$^3$) - modified proctor | AS 1289.5.2.1 | 8.9 |
| $w_{opt}$ (%) - modified proctor | AS 1289.5.2.1 | 40 |
| Hydraulic permeability (m/s) | AS 1289.6.7.2 | 1.24 E -7 |
| pH value | AS 1289.4.3.1 | 4.8 |
| Internal friction angle (degree)- Direct Shear Test ($\sigma_n$: 30-120 kPa) | BS 1377-7 | 9-10° |
| Cohesion coefficient (kPa)- Direct Shear Test ($\sigma_n$: 30-120 kPa) | BS 1377-7 | 25 |
| California Bearing Ratio (CBR) | AS 1289.6.1.1 | 1 |

Results from Direct Shear Tests (DST) indicate that the cohesion property of the samples is relatively high while the friction property is low. The low CBR value indicates the significant compressive behavior of the material.

## 4 RECYCLED GLASS-BIOSOLIDS MIXTURES

To enhance the strength of both recycled glass and biosolids their blends were investigated. It was anticipated that by mixing RG and Bio a suitable ratio of mixture could be obtained which would satisfy cohesion, friction angle and compressive strength requirements. RG-Bio blends with precentages composed of RG90/Bio10, RG80/Bio20, RG70/Bio30, RG60/Bio40, RG50/Bio50, RG40/Bio60, RG30/Bio70, RG20/Bio80 and RG10/Bio90 were tested. Figure 1 presents the particle size distribution curves of the pure materials and also the mixtures. It is apparent that the particle size distribution of the recycled glass becomes constantly finer with the addition of biosolids. The soil classification of the samples also changes from OH for pure Bio to SW-SM for pure RG.

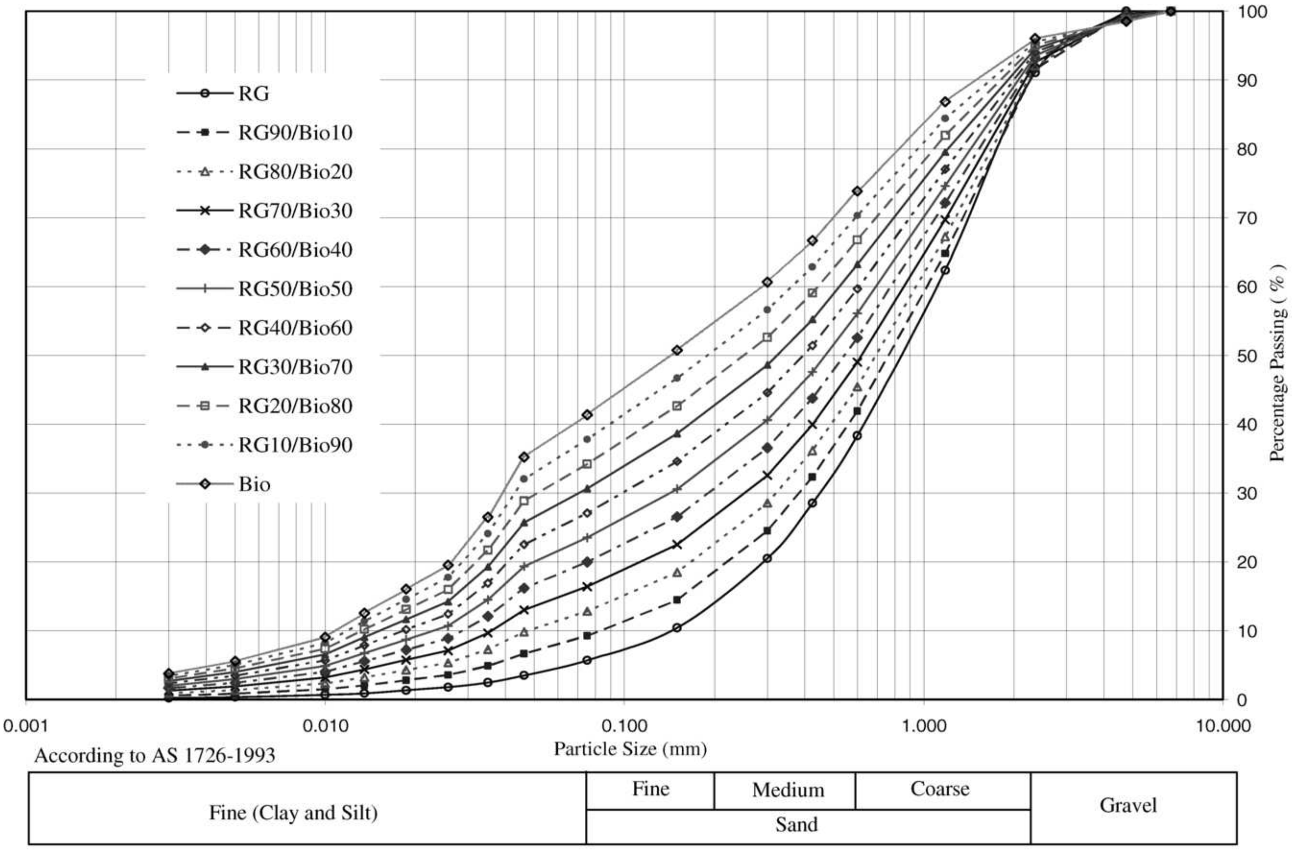

Figure 1. Particle size distribution curves of pure and blended samples

Figures 2 and 3 respectively present the standard and modified compaction curves of pure RG and Bio materials as well as that of blended mixtures. Zero air void lines for $G_s$=2.48 (pure RG) and $G_s$=1.8 (pure Bio) also have been drawn. However the value of $G_s$ will be varying with ratio of mixture between RG and Bio.

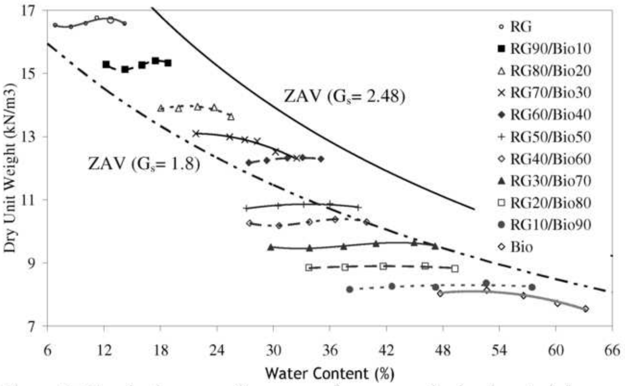

Figure 2. Standard compaction curves for pure and mixed materials

The compaction curves of pure RG for standard and modified methods were found to be similar to the compaction curves of poorly graded sand. The increase in water content results in a decrease in the dry unit weight and a subsequent increase up to the optimum water content. Capillary tension in the pore water is the main reason for the decrease of dry unit weight at lower water contents (Das 2008). The compaction curve of pure Bio is also similar to granular material categorized as OH and it is convex shaped as expected (Grubb et al. 2006). Figure 4 indicates the variation of maximum dry unit weight with the change in the RG to Bio ratio in the blended samples. 10% increase of the RG percentage in the mixture results an approximated linear increase of 9% in the maximum dry unit weight of the samples for both compaction efforts.

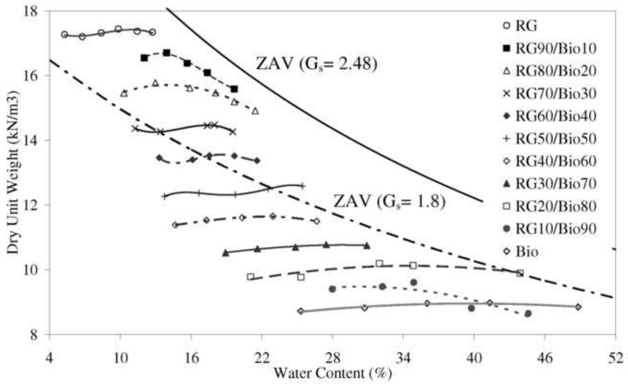

Figure 3. Modified compaction curves for pure and mixed materials

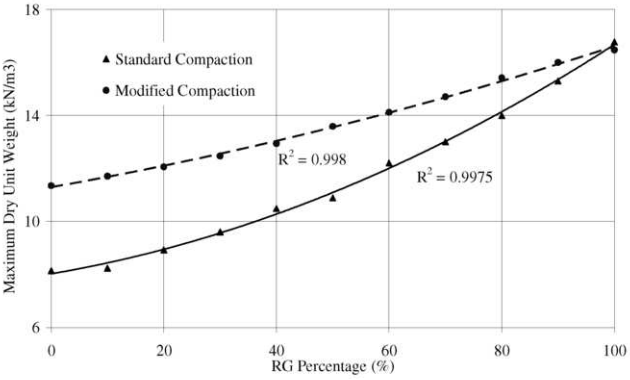

Figure 4. Maximum dry unit weight trend versus RG percentage

Figure 5 presents the changing trend in optimum water content against change in the percentage of RG in the mixtures. For the optimum water content a decrease of 3-4% was observed versus a 10% increase in the RG percentage in the mixture. Trend lines in Figures 4 and 5 represents the variation of maximum dry unit weight and optimum water content against RG percentage which were found to be polynomial curves with an order of 2. R square values indicated in Figure 4 for maximum dry unit weight relationship with the RG percentage are close to 1 and indicate a minor discrepancy. However the discrepancy between the proposed trend line and the optimum water content values resulted in lower R square values particularly for modified compaction test as indicated in Figure 5.

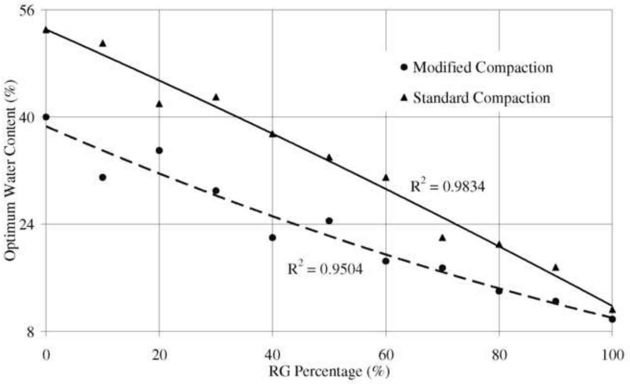

Figure 5. Optimum water content trend versus RG percentage

To assess the shear strength behavior of pure RG and Bio and the blended materials, direct shear tests were conducted on 10 by 10 cm size samples according to BS 1377-7. Essential controls were carried out to ensure that the dry unit weight of the samples was more than 95% of the maximum dry unit weight. The water contents of the samples prior to the tests were controlled to ensure that the maximum difference of the sample water content and optimum water content is limited to 2%. Figure 6 shows the variation of the cohesion coefficient (kPa) and internal friction angle (degree) of samples with the change in percentage of RG.

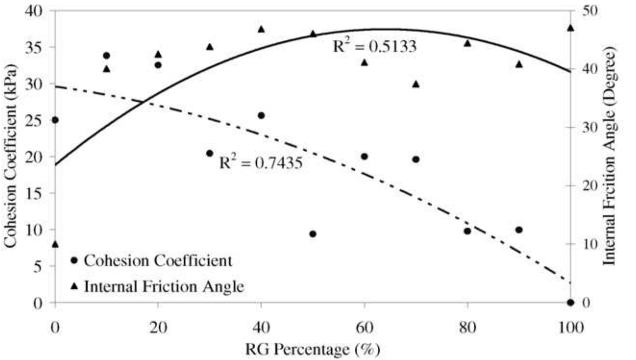

Figure 6. RG percentage effect on shear strength parameters

The increase in RG in the mixtures from 0 to 50% results in the increase in internal friction angle up to 46º. This trend continues up to RG50/Bio50 mixture which is then followed by a general decrease in all mixture except for the pure RG sample which has the highest internal friction angle. The internal friction angle represents the resistance of soil against shearing which has been produced by the frictional force developed between soil particles. Better interlocking between particles will produce a higher friction angle. On the other hand increase in the RG percentage of the mixture causes a continuous decrease in the cohesion coefficient. To determine the optimum percentages for the mixture which possesses the maximum shear strength, curves representing shear strength envelopes for various normal stress levels have been developed as shown in Figure 7.

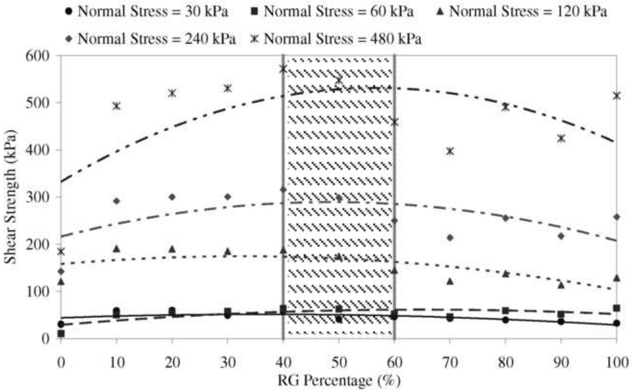

Figure 7. Shear strength envelopes versus RG percentage

The shaded area in Figure 7 shows the maximum shear strength which can be obtained for different normal stress levels. Figure 7 indicates that the maximum shear strength is achieved for RG percentage varying from 40% to 60% for all stress levels. The differences between the shear strength values for low normal stress levels is small, however this difference becomes noticeable when the normal stress level is increased from 30 kPa to 480 kPa.

## 5 CONCLUSION

An innovative idea of mixing recycled glass and biosolids in various ratios was investigated. Geotechnical tests were undertaken on the pure and blended materials. Results of DST tests indicated that RG40/Bio60, RG50/Bio50 and RG60/Bio40 mixtures possess high shear strength values which would make these blends an attractive alternative material to virgin aggregate in geotechnical applications such as embankments fills.

## ACKNOWLEDGMENT

The authors would like to acknowledge Alex Fraser Group for providing samples of recycled glass for this project and also the Smart Water Fund (Project No: 42M-2059) for funding the sampling of biosolids for this project. Authors would also like to thank Alec Papanicolaou for his technical supports during the experimental works.

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