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Resilient Modulus and Deformation Responses of Waste Glass in Flexible Pavement System

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Abstract**—**Experimental investigations are conducted to assess a layered structure of glass (G) - rock (R) blends under the impact of repeated loading. Laboratory tests included sieve analyses, modified compaction test and repeated load triaxial test (RLTT) is conducted on different structures of stratified GR samples to reach the objectives of this study. Waste materials are such essential components in the climate system, and also commonly used in minimising the need for natural materials in many countries. Glass is one of the most widely used groups of waste materials which have been extensively using in road applications. Full range particle size and colours of glass are collected and mixed at different ratios with natural rock material trying to use the blends in pavement layers. Whole subsurface specimen sequentially consists of a single layer of R and a layer of G-R blend. 12G/88R and 45G/55R mix ratios are employed in this research, the thickness of G-R layer was changed, and the results were compared between the pure rock and the layered specimens. The relations between resilient module (Mr) and permanent deformation with sequence number are presented. During the earlier stages of RLTT, the results indicated that the 45G/55R specimen shows higher moduli than R specimen.

Keywords**—**Rock base course, layered structure, glass, resilient modulus.

I. INTRODUCTION

LIVING organisms have been expelled many types of waste materials in the natural. The human population is expected to continue growing to 8.4 billion in 2030 [1]. Furthermore, the change in the living style, industrial actions, agriculture technology and much other progress caused to increase the quality and the quantity of waste. Many types of glass are used for plenty of purposes in our lives such as automobiles, architectural ob objects, and glass decorations. In general, it is easy to recycle crushed glass without losing its quality or quantity. Thus, using crushed glass in glass production costs lower than raw materials [2]. References [2] and [3] concluded that the engineering properties and many of geotechnical specification of waste glass are similar to aggregate. Further investigations were performed by [3], [4] to assess the suitability of using crushed glass as base or subbase materials in road layers. According to all above, it is an excellent opportunity to use crushed glass as foundation materials in pavement applications instead of natural base or subbase materials.

Waste materials are such vital components in the climate system, and also play a key role in minimising the need for natural materials in parts of the countries where aggregate sources are scarce. The possibility of using waste glass as unbound materials instead of natural rock or aggregate was encouraged, especially as subbase material. According to the previous research on the crushed glass, they recommended using 4.75 mm of waste glass in glass/aggregate blends, while 15% of the glass/aggregate ratio presented satisfying results of workability and shear strength, and it has been a safe ratio to use it as unbound material [5], [6]. Furthermore, the fines of glass have shown a good indication during dynamic and triaxial loads [5]. Layered structure method is one of the civil engineering applications used to assess the properties of layered soils. Many researchers investigated the effects of layered structure on the behaviour of soil specimens. References [7], [8] employed the limit analysis to study the collapse and sliding failures of the layered rock specimens.

This study is set out with the aim of assessing the performance of stratified glass-rock samples under repeated loadings. This research is a part of experimental works conducted at Curtin University, and the authors are also working on these related projects: [9], [13]-[15].

II. MATERIAL SOURCES

Crushed rock basecourse and crushed glass were collected according to ASTM and used in this study. Crushed rock was collected from Gosnells Quarry, which is one of the primary sources of rock in Western Australia. In the present research, the maximum size of crushed rock is about 20 mm. The crushed glass was obtained from Perth Bin Hire-Bayswater, and the maximum size is about 5 mm. Table I shows the physical properties of crushed rock and recycle materials used in this study.

TABLE I
PROPERTIES OF ROCK AND WASTE GLASS

Rock Type	Rock [9]	Glass [10]
Specific gravity (Gs) %	2.96	2.28
Bulk Density t/m^3	1.82	2.46
Liquid Limit %	22	----
Linear Shrinkage %	1.4	----
Organic Content %	0.47	0.7
pH	8.16	9.73
Water absorption %	7.9	0.4
Los Angeles Value %	20	25
Max Dry Density t/m^3	2.4	1.77
Optimum moisture content %	5	1.8
California Bearing Ratio %	198	41

III. EXPERIMENTAL WORK

Laboratory tests were conducted on glass, rock and blended samples including sieve analyses, modified Procter

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compaction. Furthermore, RLTT was undertaken to estimate the deformation and resilient modulus under repeated loads. Australian Soil Classification System is employed to find the gradation curve of the materials. The result was compared with the upper and the lower limitations of roads. Modified Proctor compaction test was undertaken on blends to estimate the most important parameters to prepare the RLT sample. These parameters are the optimum moisture content (OMC) and the maximum dry density (MDD) of the mixtures. RLTT was undertaken to estimate Mr which is the measure of unbound stiffness under various conditions. It also determines the permanent strain of the materials under repeated loads at many states such as moisture content, density, axial and confining pressure levels. According to [11], the stress path and the numbers of cycles of RLTT are represented in Table II. For more explanation about the structure of the RLTT specimens, Table II shows the structural details of each sample.

TABLE II
STRESS PATH DESIGN

Conditioning	Confining	Deviator	Cycles
	103.4	93.1	1000
1	20.7	18.6	100
2	20.7	37.3	100
3	20.7	55.9	100
4	34.5	31	100
5	34.5	62	100
6	34.5	93.1	100
7	68.9	62	100
8	68.9	93.1	100
9	68.9	62	100
10	103.4	124.1	100
11	103.4	186.1	100
12	103.4	62	100
13	137.9	93.1	100
14	137.9	124.1	100
15	137.9	248.2	100

TABLE III
STRUCTURAL DETAILS OF RLTT SAMPLES

Symbol	R	R+GR12	R+GR45
Specimen	R	GR(12%)	GR(45%)
	R	R	R
	R	GR(12%)	GR(45%)
	R	R	R
	R	GR(12%)	GR(45%)
	R	R	R
	R	GR(12%)	GR(45%)
	R	R	R
Symbol	2R+2GR45	4R+4GR45	
Specimen	GR(45%)	GR(45%)	
	GR(45%)	GR(45%)	
	R	GR(45%)	
	R	GR(45%)	
	GR(45%)	R	
	GR(45%)	R	
	R	R	
	R	R	

IV. LABORATORY TESTS

A. Sieve Analysis

Based on the gradation limits of [12], upper and lower limits of base course material and two of glass/rock blends are represented in Fig. 1. The results show that the curves of the mixtures are between the upper and the lower limits of base material and that would be a good indication for using the highest ratio of glass/rock which is 45% as a base course material.

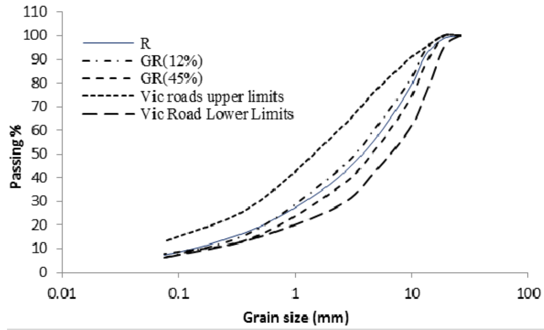

Fig. 1 Gradation curves of the materials

B. Modified Proctor Compaction Test

Table IV illustrates the results of modified Proctor compaction test for rock, glass and glass:rock blends. The results indicated that the natural rock had the highest dry density under impact energy while the G45:R55 specimen had the lowest magnitude In general, the dry density decreased as a result of glass ratio increase. Moreover, the value of moisture content became less as a result of glass increment.

TABLE IV
THE RESULTS OF MODIFIED PROCTOR COMPACTION TEST

	MDD t/m^3	OMC %
G0:R100	2.4	6
G12:R88	2.35	5.75
G45:R55	2.25	6.25
G100:R0	1.77	1.8

C. Resilient Modulus

The resilient modulus curves of pure rock and the glass/rock blends are represented in Fig. 2. The resilient modulus of R+ GR45 specimen is generally higher than the resilient modulus of pure rock. This phenomenon might be as a result of increasing the internal friction between the particles by increasing the percentage of fines. The results produce a good indication that R+GR45 performed satisfactorily at OMC and MDD module as a base material. On the other hand, blend with the lowest content of glass (R+GR12) exhibited the lowest module during all stages.

Fig. 3 shows the effect of GR45 layer thickness on the resilient modulus of the layered samples. It can be observed that, for the specimen with glass, with an increase in layer thickness, resilient modulus decreases.

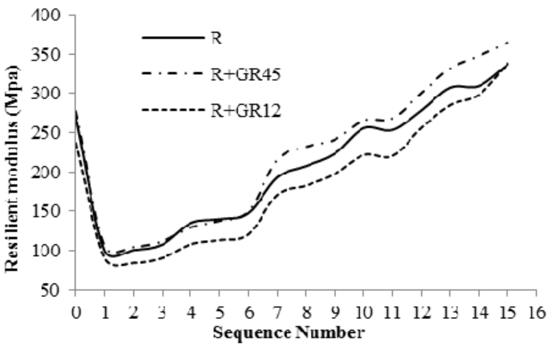

Fig. 2 Effects of glass ratio on resilient modulus

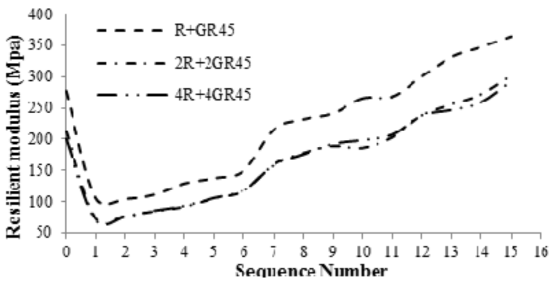

Fig. 3 Effects of layer thickness on resilient modulus.

D. Permanent Deformation

The permanent deformation curves for pure rock and glass/rock mixtures are presented in Fig. 4 for all loading sequences. The results indicate that in all loading sequences, with an increase in glass percentage, permanent deformation of the layered specimen decreases.

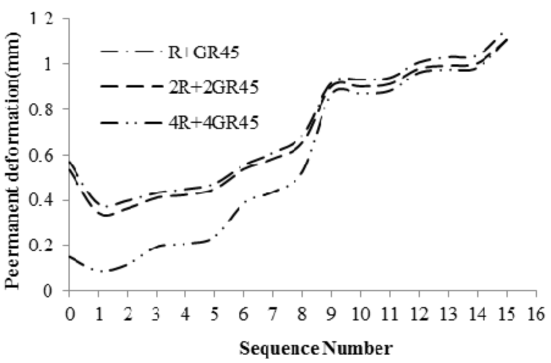

Fig. 4 Effects of glass ratio on permanent deformation

The impact of glass/rock thickness on permanent deformation of layered specimens is presented in Fig. 5. The results indicate that, with an increase in thickness of glass/rock layer, permanent deformation decreases. This phenomenon continues during all sequences, but there is a big difference between 4R+4GR45 deformation and the others during the first nine sequences. After that, the difference becomes smaller, and this might be because of an increase in confining pressure suddenly after sequence number 9.

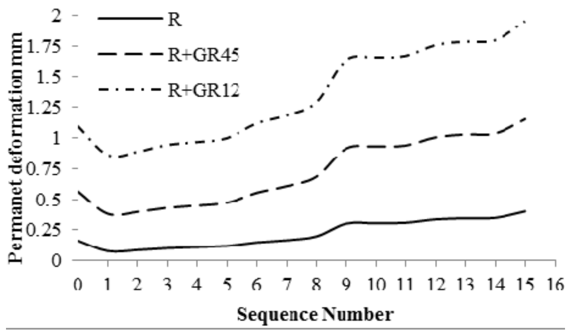

Fig. 5 Effects of layer thickness on permanent deformation

V. Conclusions

- The fine particles in the mixtures increased with an increase of glass inclusion before and after compaction stage.
- Before and after compaction stages, gradation limits of blended were satisfied with gradation limits of VicRoads.
- A significant reduction in density of glass-rock samples was associated with the glass content.
- With up to 12% glass content, a market reduction in the OMC of glass-rock sample was noticeable whereas, an increase in the OMC of the glass-rock sample appeared by increasing the glass content from 12% to 45%.
- For a low percentage of glass, with all loading sequences, the value of resilient modulus decreased, while the permanent deformation increased.
- For a high percentage of glass, with high levels of confining pressure, the value of resilient modulus increased, while the deformation value increased.
- At different glass content, a negative relationship was found between the resilient moduli of the layered samples and the GR layers.
- A market reduction in permanent deformation of the layered samples was associated with the GR layer thickness.

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References

[1] Population Reference Bureau. "2013 World Population Factsheet" (PDF). www.pbr.org. Population Reference Bureau. Retrieved 5 December 2014.

[2] Disfani, M.M., Arulrajah, A., Suthagaran, V. and Bo, M.W., 2009, October. Geotechnical characteristics of recycled glass-biosolid mixtures. In *Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering: The Academia and Practice of Geotechnical Engineering, ICSMGE.*

[3] Disfani, M., Arulrajah, A., Ali, M. and Bo, M., 2011. Fine recycled glass: a sustainable alternative to natural aggregates. *International Journal of Geotechnical Engineering*, *5*(3), pp.255-266.

[4] Arulrajah, A., Piratheepan, J., Disfani, M.M. and Bo, M.W., 2012.

Geotechnical and geoenvironmental properties of recycled construction and demolition materials in pavement sub-base applications. *Journal of Materials in Civil Engineering*, *25*(8), pp.1077-1088.
[5] Ali, M.Y., Newman, G., Arulrajah, A. and Disfani, M.M., 2011. Application of recycled glass-crushed rock blends in road pavements. *Aust. Geomech. J*, *46*(1), pp.113-121.
[6] The Australian Packaging Covenant (APC), viewed 15-April-2018; Available from https://www.google.com.au)
[7] Babiker, A.F.A., Smith, C.C., Gilbert, M. and Ashby, J.P., 2014. Non-associative limit analysis of the toppling-sliding failure of rock slopes. *International Journal of Rock Mechanics and Mining Sciences*, *71*, pp.1-11.
[8] Zhang, Q., Yin, G., Wei, Z., Fan, X., Wang, W. and Nie, W., 2015. An experimental study of the mechanical features of layered structures in dam tailings from macroscopic and microscopic points of view. *Engineering Geology*, *195*, pp.142-154.
[9] Al-saedi, M., Chegenizadeh, A., & Nikraz, H. (2017).A Study on the Layered Structure of Bentonite, Crushed Rock and Sand under Repeated Triaxial Loading. The Electronic Journal of Geotechnical Engineering, 22(4).
[10] Product_Data_Sheet_GlassSand, viewed 11 January 2018; Available from www.benedict.com.au/pdfs/Product_Data_Sheet_GlassSand.pdf.
[11] AASHTO T 307, Standard method of test for determining the resilient modulus of soils and aggregate materials.
[12] VicRoads, Standard Specifications for Roadworks and Bridge works, Section 812 Crushed Rock for Base and Subbase Pavement. Melbourne, Australia., 2010.
[13] Al-saedi, M., Chegenizadeh, A., & Nikraz, H. (2017).Dynamic Properties of Crushed Glass and Tyre Rubber in Unbound Pavement Applications. *Nominated article for Australian Geomechanics Journal (under review).*
[14] Al-saedi, M., Chegenizadeh, A., & Nikraz, H. (2017). Characterisation of the Dynamic Behaviour of waste Glass in Road Construction Evaluation of a Stratified Technique. *Nominated article for the Soil Mechanics and Foundation Engineering Journal.*
[15] Chegenizadeh, A., Al-saedi, M., & Nikraz, H. (2016). Study on the Layered Structure of Crushed Rock and Sand under Repeated Triaxial Loading. *Annual Conference on Management and Social Sciences August 9-11, 2016 Hawaii, USA*