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USE OF RECYCLED GLASS IN CONCRETE PRODUCTION

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Worldwide, rapid population growth causes an increasing production of solid waste, and sustainable waste management solutions are required to deal with this. Waste glass is a significant component of the solid waste stream, and most of the recycled glass cullet is used for new glassware. However, waste containers with mixed types of glass, such as windows, ovenware, and crystal, which have higher melting points and are of different colors, cannot be used for new glassware. Hence, the contaminated load is sent to landfill. As landfill capacity is limited, it is critical to consider using this waste material for other applications. While the effects of the substitution of fine or coarse aggregates have been extensively researched, information on the effects of partial replacement of coarse aggregates and total replacement of fine aggregate with glass cullet is scarce. This paper reports on continuing research at La Trobe University on using recycled aggregates in the production of concrete. The effects of partial or total replacement of coarse crushed rock aggregates with recycled glass aggregates on the strength and durability of concrete were investigated. It was found that concrete mixes produced with recycled glass exhibited lower performance than the mixes produced with crushed rock aggregates. However, the production costs were lower and the appearance of concrete was improved, making it applicable for finishing products, noise barriers and light-trafficked footpaths.

Keywords: Durability, Environmentally friendly, Glass cullet, Glasscrete, Laboratory investigation, Mechanical properties, Strength development, Waste glass.

1 INTRODUCTION

Modern societies require massive quantities of construction materials to build and maintain infrastructure. One of the preferred construction materials is concrete, due to its design and construction adaptability, mechanical properties, durability and economic viability (Kosmatka and Wilson, 2011). However, the extraction and processing of natural resources to produce aggregates and cement production are both energy-intensive and costly processes. Hence, the use of recycled aggregates for concrete production has become common practice to conserve natural resources, minimize environmental impacts and reduce solid waste (Ionescu 2005, Ionescu *et al.* 2015, Ionescu *et al.* 2016).

Glass is an inert material that can be recycled and reprocessed indefinitely without any loss in quality, although the recycled glass must satisfy strict specifications for a high-quality product. Glass recovery from mixed waste loads is a difficult and costly process that includes sorting by color and crushing the separated glass to form a product called cullet, which is then sent to the glass beneficiation plant. Other types of glass (flow glass, window and mirrors glass, ovenware, Pyrex, crystal, etc.), which are normally present in very small amounts (around 5 g/ton), cause contamination, and an entire load of recovered glass can end up in landfill (Randell *et al.* 2014). Moreover, automated sorting equipment tends to break the glass, and it ends up in smaller and smaller pieces until it is not readily recoverable (Randell *et al.* 2014). Hence, it is imperative to find an alternative use for the considerable quantities of broken, mixed color and contaminated glass to minimize the environmental impact.

Total or partial replacement of natural aggregates with glass cullet, as well as supplementing cementing materials with glass powder during concrete production, results in an environmentally-friendly concrete that is known as glasscrete (CCAA 2008). Successful strategies for using waste glass can be implemented if its engineering properties and its effects on the performance of concrete are established. To date, research on glasscrete performance has investigated the discrete effects of either glass powder supplement for cementitious materials and/or the substitution for fine aggregates (Omran e*t al.* 2017), and the replacement of coarse aggregates (Serniabat *et al.* 2014). Despite the positive outcomes of using recycled glass for concrete production, the processes of separating glass cullet into coarse aggregate or fine aggregate fractions, as well as grinding it down to powder to supplement the cementing materials, adds to the production costs (Serniabat *et al.* 2014). In addition, total replacement of coarse aggregate with glass cullet results in reduced concrete durability, due to the alkali-silica reaction (Omran e*t al.* 2017). Furthermore, there are no accepted specifications for the physical and chemical properties of glass cullet when used as a substitute of aggregates in concrete (CCAA 2008). Hence, this paper is focused on the performance of glasscrete produced with the partial replacement of coarse aggregates and total replacement of fine aggregate with a readily-available glass cullet.

2 MATERIALS REQUIREMENTS

Concrete comprises about 75% by volume of aggregates, which have a crucial effect on concrete properties (Neville and Brooks 2010). Past research into the possible uses of glass cullet (Spitty 2003) suggested that crushed glass has most of the required properties for concrete aggregates, i.e., it is inert, has angular grains and a broad gradation to produce a minimum voids space in the concrete matrix. Hence, it may be used as a partial or total replacement for naturally-occurring aggregates in glasscrete production.

3 EXPERIMENTAL PROGRAM

The supplied materials were subjected to physical characteristic tests in accordance with the relevant Australian Standards (primarily AS 1012, AS 1289, AS 2758) to acquire a reasonable indication of their mechanical properties. Compliance with the current specifications and the economic feasibility of obtaining the optimum material were the prevailing factors during the study.

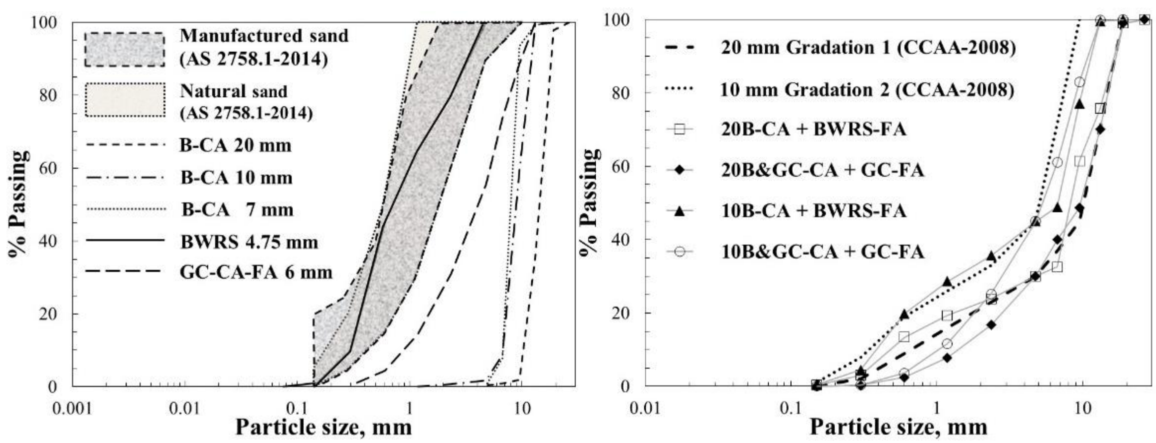
3.1 Concrete Aggregate

The aggregates were used as supplied (without additional crushing, sieving or washing), to maximize production cost savings using glass cullet. It was reported that finer-sized, green glass cullet minimizes the alkali-silica reaction (Omran *et al.* 2017). Visy supplied a green glass cullet with a nominal size of 6 mm from its glass and cardboard resource recovery plant in Melbourne. Hymix Quarry in Axedale (HQA) supplied the coarse basalt in fractions and the washed river sand in a blended state. Gradation 1 (20 mm) and Gradation 2 (10 mm) for aggregates for concrete production (Standards Australia 2014b) were used to combine the supplied aggregates as follows:

- HQA 20 mm coarse basalt and blended washed river sand (20B-CA + BWRS-FA)
- HQA 20 mm coarse basalt blended with finer than 6 mm Visy glass cullet (20B&GC-CA + GC-FA)
- HQA 10 mm coarse basalt and blended washed river sand (10B-CA + BWRS-FA)
- HQA 10 mm coarse basalt blended with finer than 6 mm Visy glass cullet (10B&GC-CA + GC-FA).

This resulted in a total replacement of natural sand with glass cullet, whereas the coarser aggregates were replaced in proportions of 31.2% to 34.3% by waste glass for the 10 mm and 20 mm maximum grain size gradations, respectively.

Figure 1(a) presents the gradation for the materials supplied for this research, compared with the current specifications for both natural and manufactured sand. The blended washed river sand (BWRS) sand fits well between the boundaries of both natural and manufactured sand, whereas the glass cullet (GC) is parallel to the coarser boundary for sand, and comprises 45% by weight of fractions coarser than 4.75 mm. Figure 1(b) shows the CA + FA combined gradations against the ideal Gradation 1 for a maximum aggregate size 20 mm and the ideal Gradation 2 for a maximum grain size 10 mm, respectively. Both gradations containing glass cullet (20B&GC-CA + GC-FA and 10B&GC-CA +GC-FA) are below the ideal gradations, indicating that they lacked fines, particularly the fractions between 2.36 mm and 0.6 mm. The chemical composition of the glass cullet is presented in Table 1. The BWRS fines (grains < 0.425 mm) were tested for any clay content. A summary of the consistency tests (Standards Australia 2009) and the clay and silt contents (Standards Australia 2015) is presented in Table 2. It was found that the finer fractions classify as non-plastic/low plasticity silts. In addition, the physical properties of both coarse and fine aggregates were determined in accordance with the relevant specifications (AS 1141.6.1 2000), and they are summarized in Table 3. As expected, the glass cullet was inert to water absorption, and it was only 4% to 11% lighter than the basalt and blended washed river sand, resulting in a concrete with comparable properties to concrete produced with natural aggregates.



(a) (b)

Figure 1. Particle size distribution of aggregates used to prepare the concrete specimens: (a) supplied aggregates; (b) combined gradations (CA + FA) for both nominal sizes 20 mm and 10 mm, respectively.

Table 1. Chemical composition of the glass cullet supplied from Visy.

SiO_2 (wt%)	Al_2O_3 (wt%)	Fe_2O_3 (wt%)	CaO (wt%)	Na_2O (wt%)	MgO (wt%)	K_2O (wt%)	Cr_2O_3 (wt%)	MnO (wt%)	TiO_2 (wt%)	SO_3 (wt%)	P_2O_5 (wt%)
67.8	1.53	0.36	10.93	11.09	1.58	0.55	0.1	0.018	0.062	0.03	0.023

Table 2. Consistency characteristics and silt content in fine aggregates.

Material	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Linear shrinkage (%)	Silt content (%)
BWRS-FA	18	14	4	2	6
GC-FA	1	NP	-	0	4

Table 3. Physical properties of aggregates used.

Material	Water absorption (%)	Moisture content (%)	Particle density SSD (t/m^3)
B-CA	2.23	3.0	2.72
GC-CA	-	-	2.41
BWRS-FA	0.6	7.5	2.61
GC-FA	-	-	2.51

3.2 Concrete Strength

The quantities for the four concrete mixes were based on a nominal characteristic compressive strength of 32 MPa and are listed in Table 4. Concrete was produced with Portland cement and aggregates in as-supplied conditions. The mix design used a 50-mm slump, and the water quantities for concrete preparation were corrected for the moisture content of the natural aggregates.

Table 4. Proportions used for the mix design.

Mix type	Cement (kg)	Water (kg)	Fine aggregates(kg)	Coarse aggregates (kg)
20B-CA + BWRS-FA	370	158	550	1270
20B&GC-CA + GC-FA	370	196	870	790
10B-CA + BWRS-FA	390	160	780	950
10B&GC-CA + GC-FA	390	212	1240	300

Table 5 summarizes the strength at 7 days and 28 days. Glasscrete produced a lower strength when compared with the control batches, with strength reductions of 29.7% (20B&GC-CA + GC-FA) and 40.8% (10B&GC-CA + GC-FA) at 7 days. At 28 days, the strength of the glasscrete was 35.1% (20B&GC-CA + GC-FA) and 46.6% (10B&GC-CA + GC-FA) lower than that of the control concrete. The trend was similar for the flexural and splitting tensile strengths.

Table 5. Average strength of hardened concrete.

Mix type	7 days			28 days		
	f_{cm} (MPa)	$f_{ct.f}$ (MPa)	$f_{ct.sp}$ (MPa)	f_{cm} (MPa)	$f_{ct.f}$ (MPa)	$f_{ct.sp}$ (MPa)
20B-CA + BWRS-FA	45.5	4.1	2.4	57.0	5.3	4.3
20B&GC-CA + GC-FA	32.0	3.4	2.0	37.0	4.0	2.5
10B-CA + BWRS-FA	51.7	4.3	2.6	65.5	6.2	4.5
10B&GC-CA + GC-FA	30.5	3.3	2.0	35.0	3.7	2.4

Note: measured f_{cm} = mean compressive strength, $f_{ct.f}$ = flexural tensile strength, $f_{ct.sp}$ = splitting tensile strength

3.3 Durability of Concrete

An indirect correlation exists between the durability of concrete and the water permeable voids present in the hardened concrete. The water absorption and the apparent volume of permeable voids were determined from tests performed in accordance with Australian Standards (Standards Australia 2014a), and the results are summarized in Table 6. The 20B&GC-CA + GC-FA mix showed a reduction, whereas the 10B&GC-CA + GC-FA mix showed a slight increase in the apparent volume of permeable voids.

Table 6. Apparent volume of permeable voids for 28 days old concrete.

Mix type	Immersed absorption (%)	Boiled absorption (%)	Apparent volume permeable voids (%)
20B-CA + BWRS-FA	7.0	7.1	16.1
20B&GC-CA + GC-FA	7.3	7.7	15.2
10B-CA + BWRS-FA	6.8	6.9	15.7
10B&GC-CA + GC-FA	6.7	7.2	15.2

4 CONCLUSIONS

The effects of the partial replacement of coarse aggregates and the total replacement of natural sand with glass cullet for concrete production were discussed in this paper, and the following conclusions can be drawn.

The use of waste glass resulted in a significant reduction in the strength of the design batches, although they satisfied the design compressive strength requirements. This trend was also observed for the flexural and splitting tensile strength of glasscrete. The durability of the glasscrete was also affected, with both measurements for water absorption showing increased values. The apparent volume of permeable voids results was inconclusive, as they contradict the trends observed for water absorption.

Partial replacement of coarse natural aggregates and total replacement of natural sand with glass cullet appear to be suitable solutions for concrete production, although, their use may result in a less-durable concrete, due to a slightly higher volume of permeable voids. However, the cost of production of concrete with recycled glass aggregates is lower than that of natural aggregate concrete, while providing environmental benefits. Furthermore, the appearance of glasscrete makes it attractive for architectural applications such as finishing products, noise barriers and low trafficked footpaths.

The strength of glasscrete may be improved if partial replacement of fine aggregates is used instead of total replacement. Additionally, the durability of concrete may possibly be improved if water-repellent admixtures are added to the mix. Future research is required to study these aspects.

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References

Cement Concrete and Aggregates Australia (CCAA), *Use of Recycled Aggregates in Construction*, CCAA Publications, Sydney, 2008.

Ionescu, D., Construction Potential of a Mining By-Product, *Achieving Sustainability in Construction*, Dhir, R. K., Dyer, T. D. and Newlands, M. D. (eds), 169-176, Dundee, United Kingdom, 2005.

Ionescu, D., Petrolito, J., Forrest, J., German, S. and Pinnuck, S., Effects of Alternative Aggregates on Concrete Strength, *Interaction between Theory and Practice in Civil Engineering and Construction*, Komurlu, R., Gurgun, A. P., Singh, A., Yazdani, S. (eds), ISEC Press, 2016.

Ionescu, D., Petrolito, J., Mainali, B., Sweet, J. and Robinson, D., Alternate Aggregates for Concrete, *Science, Engineering and Environment*, Vol. 1, Hossain, Z. and Kaneco, S. (eds.), 318-323, Tsu, Mie, Japan, 2015.

Kosmatka, S. H. and Wilson, M. L., *Design and Control of Concrete Mixtures: The Guide to Applications, Methods and Materials*, Portland Cement Association, USA, 2011.

Neville, A. M. and Brooks J.J. *Concrete Technology*, Pearson, United Kingdom, 2010.

Omran A. F., Morin, E. D., Harbec, D., Tagnit-Hamou, A., Long-Term Performance of Glass-Powder Concrete in Large-Scale Field Applications, *Construction and Building Materials*, 135, 43–58, January, 2017.

Randell, P., Pickin, J. and Grant, B., Waste Generation and Resource Recovery in Australia, *Reporting Period 2010/11*, 4 February 2014.

Serniabat T. S., Khan, M. N. N. and Zain, M. F. M., Use of Waste Glass as Coarse Aggregate in Concrete: A Possibility towards Sustainable Building Construction, *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, 8(10), 1071-1078, 2014.

Spitty, A., *The Use of Recycled Glass as Aggregate in New Concrete*, La Trobe University, Bendigo, Australia, 2003.

Standards Australia, *Methods of Testing Soils for Engineering Purposes, AS 1289*, Standards Australia, Sydney, Australia, 2009.

Standards Australia, *Methods of Testing Concrete – Determination of water absorption and apparent volume of permeable voids in hardened concrete, AS 1012.21*, Standards Australia, Sydney, Australia, 2014a.

Standards Australia, *Aggregates and Rock for Engineering Purposes - Concrete Aggregates, AS 2758.1*, Standards Australia, Sydney, Australia, 2014b.

Standards Australia, *Methods of Sampling and Testing Aggregates Methods for sampling and testing aggregates, AS 1141.6.1, AS 1141.33*, Standards Australia, Sydney, Australia, 2015.