Studies on recycled waste glass powder as binder in concrete

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Abstract. *The present study deals with the experimental investigation on recycled waste Glass Powder (GP) as a pozzolanic cement. Two particle sizes of 75 μm and 150 μm were used for the current study. The considered GP replacement levels were 0%, 20%, 40%, 60% and 80% by weight of cement and workability, density, compressive and tensile strengths were investigated. Test results show that GP as a partial cement replacement has proven feasible for low strength and light weight applications. In addition, GP can be used in places where there is higher demand for workability. Further research into hardening over longer periods and low strength applications, GP concrete could become a sustainable option for industry.*

Keywords: glass powder; cement replacement; pozzolanic behavior; Compressive strength

1 INTRODUCTION

Concrete is one of the most used material in the world, global production rates are rising annually to meet the ever increasing demand. Since cement is the main ingredient in concrete, it is manufactured in enormous quantities. It is estimated that around 85.9 million metric tons of cement is produced in United states alone in comparison to a staggering 4,200 million metric tons worldwide (US Geological Survey, 2017). Gopalakrishnan and Govindarajan (2011) suggested replacing cement with either a solid waste material or industrial by-product as a practical solution for decreasing the Portland cement consumption thereby, reducing the environmental and energy impacts associated with the concrete production. Use of industrial by-products like fly ash from coal combustion, or silica fume from silicon and ferrosilicon alloy production, or blast furnace slag from pig iron production, as cement substitution represents a value-added methodology to address the environmental issues. Hence, there is an increasing demand in utilizing the recycled materials in the construction industry for promoting sustainability and green construction (Arulrajah et al., 2015; Liu et al., 2015; Lopez-Gayarre et al., 2015; Lotfi et al., 2015; Shang et al., 2015; Silva et al., 2015).

In recent years, use of recycled material such as waste glass has received an augmented attention in the concrete industry (Wang et al., 2009; Jain and Neithalath, 2010; Nassar and Soroushian, 2012). At first, waste glass was used as an aggregate replacement in concrete and it was observed that the mechanical and durability properties of the modified concrete were degraded due to the increased potential of Alkali-Silica Reaction (ASR) (Etris et al., 1974; Topcu and Canbaz, 2004; Saccani and Bignozzi, 2010). The main reason for this deterioration

was due to high percentage of silica in glass cullets which increased the chances of ASR in the concrete. Taha and Nounu (2008) explained that ASR is a deleterious expansion occurring in concrete due to the reaction between siliceous minerals present in aggregate and the alkaline pore solution in concrete. Later, Investigations have shown that ASR occurrence in concrete is dependent on the particle size distribution of glass used, as the particle size decreases the ASR probability reduces (Shao et al., 2000; Shayan and Xu, 2004). The suppressive effect of glass powders on the ASR expansion in concrete was due to the pozzolanic characteristic of glass powder, similar to other pozzolanic materials such as fly ash, silica fume and metakaolin (Duchesne and Berube, 1994; Ramlochan et al., 2000). These results, motivated the use of recycled glass powder with microscopic particle size distribution as cement replacement. There are multiple benefits of using recycled glass powder as cement replacement: firstly, using a waste material would reduce the load on the landfills, secondly, the total cost would be less as a recycled waste glass powder is replacing the costly cement and finally, the use of recycled glass powder would lead to an sustainable construction since decreasing the cement manufacturing.

Experimental investigations have reported that glass when grinded to about 300 μm showed negligible ASR and these findings are in agreement with the maximum particle size of 300 μm for ASR occurrence (Shayan and Xu, 2004; Farshad et al., 2010; Du and Tan, 2013; Du and Tan, 2014). Mehta (2002) stated that the glass particles start to behave as a pozzolanic material at approximately below 300 μm and when the fineness is reduced to about 100 μm the pozzolanicity of the glass exceeds that of fly ash at low cement replacement levels and after curing of 90 days. The pozzolanic property of glass increases with the fineness of the glass, as the particle size distribution reduces the pozzolanic ability of the glass increases. Studies as early as 2000, have been reported in the literature pertaining to the GP as cement replacement and the size of the glass particle used ranged from 0-150 μm (Shao et al., 2000). Of late, the researchers concentrated on finer glass particle size ranging from 0-100 μm and the maximum percentage of cement replacement is 60% (Du and Tan, 2015; Kamali and Ghahremaninezhad, 2016; Omran and Tagnit-Hamou, 2016; Du and Tan, 2017). There is no consensus about the ideal cement replacement percentage, as the performance of the glass powder concrete is dependent on various factors including: the particle size distribution and chemical composition of the glass.

In this paper, an experimental investigation into the effect of two glass powders of different fineness on workability, density, compressive and tensile strength of cementitious materials is presented and the performance of these glass powders is compared with a reference mix made with a conventional Portland cement. The glass powders examined in this paper had different fineness, hence allowed investigating the dependence of cementitious material behaviour on the size of the glass powders. As stated in the previous section, the substitution content of cement by GP is limited to 60%, the present experimental work consists of replacing higher volume of GP (>60%) as cement replacement in order to check the suitability of GP as a binder by itself rather than a cement replacement.

2 EXPERIMENTAL PROGRAM

2.1 MATERIALS

The cement used in this project was general purpose cement which complies with all the regulations and requirements highlighted in AS 3972 for general purpose and blended cement. Glass powder used in the current study was obtained from a recycling centre. Recycled glass powder was obtained by crushing waste glass bottles (such as liquor bottles and soft drink bottles) which were obtained from the local landfill site in the city of Brisbane, Qld, Australia. Cone crusher was used to grind the glass powders to the desired fineness. Two types of glass powders, GP1 (fine glass powder - 85 % < 75 μm) and GP2 (coarse glass powder - 95 % < 150 μm) were used as a high volume binder replacement in the present project. Fine aggregate passing 4.75 mm sieve was used in the preparation of the mixtures with a specific gravity of 2.69, water absorption of 1.89% and fineness modulus of 2.78.

2.2 MIX DESIGN

Glass powders, GP1 (<75 μm) and GP2 (<150 μm) were used as high volume cement substitution (up to 80%), unlike previous studies in which the replacement level of GP was limited to 60%. A constant water to cementitious material ratio of 0.4 was applied, binder and fine aggregate content used in the mixes were fixed at 600 kg/m^3 and 630 kg/m^3 respectively. GP1 was used as cement replacement at 20%, 40%, 60% and 80% by mass. Since, the 80% substitution didn't yield acceptable outcome the replacement of GP2 was limited to 60%. The mix with 0% GP is considered as a reference mix (REF) to compare the performance of the glass powders. Mix design used in the experiment is shown in Table 1.

Table 1 Mix proportioning corresponding to a volume of 1 m^3 of concrete

Mix Design	Cement (kg)	GP1 (<75 μm) (kg)	GP2 (<150 μm) (kg)	Cement replacement (%)	Fine Aggregate (kg)	Water (kg)
Control	600	-	-	0	630	240
GP1-20	480	120	-	20	630	240
GP1-40	360	240	-	40	630	240
GP1-60	240	360	-	60	630	240
GP1-80	120	480	-	80	630	240
GP2-20	480	-	120	20	630	240
GP2-40	360	-	240	40	630	240

2.3 SPECIMENS

Concrete cylinders of dimension 100 mm (diameter) and 200 mm (height) were prepared in accordance with AS 1012.8.1. Cylindrical moulds were filled in two approximate equal layers and compaction was done by rodding 25 strokes per layer. Concrete cylinders were cured in a moist room at more than 95% relative humidity and at a temperature of $23 \pm 2^\circ\text{C}$ for 24 h, and then demolded, identified and immersed in limewater bath until testing time. This process of curing is compliant with the Australian standard AS 1012.

3 RESULTS & DISCUSSIONS

3.1 WORKABILITY (AS 1012.3.1)

The slump of all the mixes modified with the two glass powders GP1 & GP2 compared with the reference mix is shown in the Figure 1. It is evident from the Figure 1 that the slump of the mix increases with glass powder replacement up to certain percentage (40%-GP1 & 60%-GP2) of glass powder substitution irrespective of the glass powder used compared to the reference mix. The trend of slump is similar in both the glass powders, after an initial increase at 20% replacement there is a decline in the slump. This pattern of initial increase and then decrease in the workability is reported by the previous studies by Sharifi et al. (2015). All the mixes regardless of the GP replaced exhibited slump values greater than the reference with the exception of mix GP1 at 80% replacement. The mix with GP2 at 20% substitution recorded the highest value of the slump which was approximately three times the slump of reference mix.

Figure 1 Workability of mixes

3.2 HARDENED DENSITY (AS 1012.12)

The densities of all the mixes in hardened state are depicted in Figure 2. The densities of the mixtures modified with the GP1 & GP2 decreased compared to the reference mix, this reduction is proportional to the substitution percentage. 80% replacement yielded the least density out of all the modified mixes with a decreasing value of about 16%. Stage two mixes resulted in a maximum reduction of 11% at 60% substitution level. Comparing the density values taken at both the intervals, it is noted that the 28-day densities of all the mixes was greater than the 7-day with an exception of mix GP1-80. This characteristic of reduction in the density can be effectively used where there is a need of light weight concreting.

Figure 2 Density of mixes

3.3 COMPRESSIVE STRENGTH & STRENGTH ACTIVITY INDEX (AS 1012.9)

The compressive strength test results of all the concrete mixes at 7, 28 and 91 day curing ages are shown in Figure 3. There is a linear decrease in the strength regardless of the glass powder employed, 80% replacement yielded the lowest strength which was less than 10% of the reference at 28 days. As stated earlier, since the pozzolanic activity of the GP is inversely proportional to the size, the performance of GP1 is consistently better than GP2 throughout the replacement levels. The decrease in compressive strength with the addition of GP is not necessarily a poor result as the 20% replacement resulted in a concrete strength 50 MPa. Although this is less than the control it is still strong. This allows for 20% less cement to be used in cases where 50 MPa is the target strength. At 20% substitution, both the glass powders GP1 and GP2 exhibited almost similar strengths at respective curing ages. These outcomes are in agreement with the past studies reported in the literature wherein the optimum replacement content was 30% owing to the shortage of CH (Calcium Hydroxide) which is essential for the pozzolanic reaction for producing secondary C-S-H (Calcium Silicate Hydrate) (Du and Tan, 2017).

Figure 3 Compressive strength of mixes

The pozzolanic performance of GP may be estimated with the Strength Activity Index (SAI), which is the ratio between strength of mortar containing GP and strength of equivalent reference mortar at the same age. The strength activity indexes of all the GP modified mixes is illustrated in the Figure 4. The best SAI was obtained at 20% replacement in both the GP's and the value decreased with the increasing replacement percentage in all modified mixes. The SAI values of GP1-20 are 76% and 79% at 28 and 91 days respectively. Since the SAI of the mix GP1-20 is greater than 75%, it can be treated as a pozzolan according to the standard ASTM C618-05, (2005). The mix GP2-20 was also not far behind as it showed a SAI values of 73% and 75% at 28 and 91 days respectively. Shi et al. (2005) reported similar results with a 20% GP replacement and the SAI obtained was around 74% at 28 days. These results indicate that the maximum pozzolanic activity of the glass powders used in the current research was obtained at 20% replacement.

Figure 4 Strength activity index at 28 and 91 days

3.4 TENSILE STRENGTH (AS 1012.10)

Figure 5 provides the results of 7 and 28 day tensile strength of GP2 at various substitution levels and compares it with the reference mix. Similar to the compressive strength, there is a linear decrease in the tensile strength with the increase in replacement percentage. Out of all the glass powder modified mixes tested, 20% replacement gave the best results.

Figure 5 Tensile strength of mixes

4 CONCLUSION

This study reported experimental results on the use of two recycled glass powders, GP1 and GP2 as supplementary cementitious material in concrete. Unlike previous work, this study examined the effects of a higher GP replacement of up to 80%. Based on the newly obtained results, the following conclusions can be drawn:

- Both the glass powders used in the study followed a similar pattern in workability, after an initial increase at 20% replacement the workability reduced at higher substitution levels;
- The hardened densities of the mixes modified with the GP1 and GP2 yielded lesser values compared to the reference conventional Portland cement indicating a possibility of using the glass powder for light weight structures;
- Apropos the compressive strength, GP1 at 20% replacement outperformed other modified mixes, nonetheless the performance reduced at higher substitution levels and the strength values were almost similar to GP2;
- Both the glass powders, GP1 & GP2 at 20% substitution exhibited a SAI values greater than 75 at 91 days of curing and hence can be used as a pozzolanic cementitious material;
- Tensile strength followed a similar trend like compression and 20% replacement was ideal for the glass powder under examination; and
- Since GP increased workability, further research could be done by decreasing water cement ratio so as to increase the compressive strength of the GP modified concrete.

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