EFFECTS OF USING GLASSWASTE CULLETS AS AGGREGATES IN CONCRETE

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ABSTRACT

Glass recycling in South Africa is actively employed to promote environment sustainability. However, considerable quantities of waste are generated during this recycling process, which is disposed-off to landfills. The present study was conducted to investigate potential use of glass waste cullets in concrete. Concrete of water/cement ratio = 0.75 was used to prepare 100 mm (4 in.) cubes, 100 x 100 x 200 mm (4 x 4 x 8 in.) double cubes and 50 x 50 x 285 mm (2 x 2 x 11.4 in.) prisms. Control mixtures were made using crushed granite coarse and fine aggregates, then glasswaste cullets were incorporated as sand replacements in proportions of 0, 30, 50 and 70% glass. Tests conducted include workability, compressive strength, elastic modulus and drying shrinkage. It was found that workability and drying

shrinkage properties decreased due to use of glass. There was also reduction in compressive strength with increase in proportion of glasswaste incorporated into mixtures. However, mixtures containing 30% glass maintained substantial strength behaviour.

Keywords: Glass cullets, alkali-silica reaction, fine aggregates, compressive strength, recycling, waste management, glasscrete, shrinkage

INTRODUCTION

Glasswaste is post-consumer by-product that may not be re-used in the bottling industry[1]. Large quantities of glasswaste is disposed-off in various landfill sites around South Africa, which takes up a lot of land space. It has been estimated that about 550 000 tons of glasswaste ends up in landfills rather than being recycled. However, glass can be recycled numerous times without major impacts on quality of the end product.

The recycled glasswaste, also referred to as *cullets*, can be used for several applications. The amount of glass consumed in South Africa is in excess of 3.1 million tons, of which two-thirds could be prevented from disposal to landfills. Furthermore, it is recognised that glass contributes about 4.5% of the total waste production. Various solutions have to be investigated to make the reuse of glass cullets an economical option that is viable and sustainable. One such possibility is the use of glass waste as aggregate substitute in concrete.

Glasscrete is a product resulting from incorporating glass waste in concrete, usually as fine aggregate[1]. By using glasswaste in this manner, large quantities of these cullets that would have been disposed-off in landfills, can be employed in concrete construction. This is one way of improving and preserving the environment, conserving raw materials and achieving sustainability, being the advantages of recycling. Accordingly, sustainability provides a real potential for re-using large quantities of waste materials[2,3].

Although use of glass cullets might be advantageous for the environment and conservation measures, there are also disadvantages that come with its use in concrete. One of the major problems encountered from using glass in concrete, is its susceptibility to expansion and cracking due to Alkali-Silica Reaction (ASR). This mechanism arises when reactive phases in aggregates interact with alkalis in cement forming expansive gel under moist conditions[1,4]. Due to its natural characteristics and manufacturing processes, glass reacts with alkalis in pore solution of concrete, resulting in expansion and formation of cracks within concrete. To mitigate this disadvantage, glass cullets can be finely ground and used as a supplementary cementing material.

Glass aggregates are considerably different from conventional aggregates used in concrete, in that they are manufactured and not natural materials. As a result, the chemical composition of glass can vary considerably[5] and may have different effects on the characteristics of concrete including compressive strength, tensile strength, modulus of rupture, ASR, amongst others. In the present study, the potential use of South African glass cullets as fine aggregate in concrete, was investigated.

RESEARCH SIGNIFICANCE

In this study, glasswaste which is often disposed-off to landfills, was evaluated for potential use in concrete. Waste management and recycling have become important issues in ensuring sustainability, due to the increasing amount of waste generation, shortage of landfills and environmental pollution effects of waste disposal. In this investigation, scientific understanding is generated in this regard.

EXPERIMENTAL MATERIALS AMD METHODS

In the experiments, glass cullets were used as fine aggregate or sand in concrete mixtures. Granite sand was replaced using the glass cullets, in proportions of 0, 30, 50, 70 and 100% glass. Normal portland cement (CEM I 52.5 N) supplied by Pretoria Portland Cement (pty) Ltd was used in the study along with granite coarse aggregate of 13.2 mm (0.53 in.) size. Fresh and hardened concrete properties were measured including workability, compressive strength, elastic modulus and drying shrinkage.

Preparation of glass cullets

Glass cullets used in the study were obtained from Consol (pty) Ltd. The glass was already crushed and no further size reduction took place in the laboratory. The dust contained in the glass was washed-off through a 75 μm (No. 200) sieve, using clean tap water. After washing, the cullets were allowed to dry overnight at room temperature in the laboratory. Sieve analysis was conducted on crushed granite sand and on glass cullets, in accordance with ASTM C 136 Standard test method for sieve analysis of fine and coarse aggregates. **Fig.1** shows features of glass cullets used in the study. It can be seen that the material consisted of various colours and sizes. The particle sizes of the cullets were compared to those of crushed granite sand as shown in **Fig. 2**. Relative to the control granite sand, it is evident that the glass had less fines of sizes 0.30 to 1.18 mm (sieve No. 50 to No. 16) and more coarse fractions greater than 2.36 mm (No. 8). These differences in particle size distributions may have an influence upon workability and strength properties.

Concrete mixtures and test procedures

Concrete mixtures of water/cement = 0.75, were made using crushed granite fine aggregate or up to 100% glass as fine aggregate replacement. All samples were moist-cured in water for 28 days and then used to conduct various tests. A slump test was conducted to assess workability of fresh concrete mixes. Hardened concrete testing involved compressive strength done using 100 mm cubes at 7, 28, 56, and 90 days. Drying shrinkage test was conducted in accordance with SANS 5836[6] using 50 x 50 x 285 mm (2 x 2 x 11.4 in.) prisms following 28 days of curing, while stress-strain behaviour was determined using 100 x 100 x 200 mm (4 x 4 x 8 in.) prisms.

RESULTS AND DISCUSSION

Influence of glass waste on workability

The results given in **Fig. 3** show the slump of concrete to generally decrease as the proportion of glass waste increased. This effect appears contrary to the understanding that washed glass is typically, smooth and free of dust which would ensure negligible water absorption relative to crusher sand. These characteristics would be expected to promote better flow properties of fresh concrete containing glass aggregates[5]. The observed slump test results, however, contradict the reports of Mageswari and Vidivelli[7] who found that workability of concrete increased as the proportion of glass increased. However, water absorption, texture and dust content are just some of the factors influencing workability. In this investigation, particle size distribution and angularity are thought to be among the two factors that majorly influenced the measured workability of concretes containing glass. The shortage of particles in the range of 0.30 to 1.18 mm (sieve No. 50 to No. 16) and correspondingly high proportion of coarse particles in the range of 2.36 to 4.75 mm (No. 8 to No. 4) within the glass cullets, appears to have resulted in harsh mixes, which exhibited significant aggregate interlocking and consequent reduction of flow characteristics. These effects are notable in **Fig. 4** which clearly shows proper slump behavior for control mix made using granite sand and a harsh mix, characterized by shear failure for the mixture containing 70% glass cullets. These observations are also consistent with the findings of Adaway and Wang[8] who reported that slump decreased as a result of using waste glass into concrete, the effect becoming more pronounced with increase in proportion of glass used in the concrete. They also indicated that glass could promote segregation and bleeding of concrete.

Compressive strength results

Compressive strength was measured for ages of up to 90 days. At each age, three cubes that had been stored under water during curing, were tested. The compressive strength results in **Fig. 5** show that the control, comprising natural crushed granite sand produced 28-day compressive strength of 30 MPa (4351 psi). Both early-age and late-age strengths decreased as the proportion of glass replacement increased. The 30% glass content gave 28-day compressive strength of 25 MPa (3626 psi), a strength reduction of 12% which is quite acceptable. At the age of 90 days, this strength reduction was 11%, which is similar to that at 28 days. Similarly, the 50% and 70% glass mixes had strength reductions of 17.6% and 31% at 28 days, which remained generally unchanged at 90 days giving reductions of 17.5% and 29.1% respectively. However, the mixture of 100% glass showed significant strength decrease of 44.6% at 90 days compared to 35.2% reduction at 28 days. It appears that this late-age strength decrease in 100% glass mix may be related to ASR, whose attack could have presumably started to affect strength in this mixture of high glass content, relative to its delayed influence in the mixtures containing lower glass contents. ASR is, however, a chemical deterioration mechanism. The general strength decrease observed from early to late ages as a result of incorporating glass, was a mechanical effect attributed to strength and shape characteristics of glass. Wright[1] attributed this mechanical effect to the generally flat and elongated shape of coarse glass particles whose surfaces are less likely to form stronger bonds and interfaces with cement paste matrix.

The experimental results in this study agree with findings of Mageswari and Vidivelli[7] who also conducted a similar study using 30, 40 and 50% glass powder as partial replacement for fine aggregate. They also reported decrease in compressive strength with increase in proportion of glass used. Vanjare and Mahure[9] also reported compressive strength decrease with increase in glass content of self-compacting concrete.

Stress-strain behaviour

The influence of glass on stress-strain behavior of concrete is shown in **Fig. 6**. It is clear that there is decrease in elastic modulus of concrete in proportion with increase in glass content. These results are consistent with the compressive strength results reported in the foregoing. The reduction in elastic modulus is similar to effect of glass on compressive strength, and may be attributed to weaker aggregate-paste bond due to smooth surface of glass aggregate.

Drying shrinkage results

Fig. 7 gives the shrinkage measurements conducted for ages of up to 90 days. Mixtures of 0, 70% and 100% glass were used in the shrinkage measurements conducted in accordance with SANS 5836[6]. It is seen that shrinkage behaviours were similar in the first 30 days but in the long-term, the glass concrete gave generally lower shrinkage compared to control. Dumitru et al.[11] found increase in drying shrinkage when glass powder was used as cement replacement but decrease when used as sand replacement material. Du and Tan[10] also reported decrease in drying shrinkage when glass was used as fine aggregates. The shrinkage reduction observed when glass was used as fine aggregate may be attributed to its negligible water absorption and therefore the aggregate provides no major contribution to water loss during the drying episode. In addition, the strong interlocking characteristics of glass may also inhibit interparticle movement generated, accordingly contributing to shrinkage reduction.

CONCLUSIONS

The present study examined the influence of glass when used as a fine aggregate in 30 MPa (4351 psi) concrete in comparison to control made using granite sand and stone. No replacement was made on coarse granite aggregate. Glass cullets were used in the same gradation as obtained from industry, and had less finer particles of sizes 0.30 to 1.18 mm (No. 50 to No. 16) but more coarse particle sizes, than the standard crusher granite sand typically used in concrete. Use of the glass cullets as sand replacement led to decrease in workability of the concrete mixtures.

Compressive strength of concrete decreased as the proportion of glass incorporated increased. Use of 30% glass gave strength reduction of about 12%, representing a 28-day strength reduction from 30 MPa to 25 MPa (4351 to 3626 psi), which may be considered acceptable. At the high proportion of 100% glass, strength at later ages appeared to decrease more rapidly, presumably due to onset of alkali-silica reaction. The trend of stress-strain behavior was similar to the findings on compressive strength. Also, there was decrease in drying shrinkage as a result of using the glasswaste cullets.

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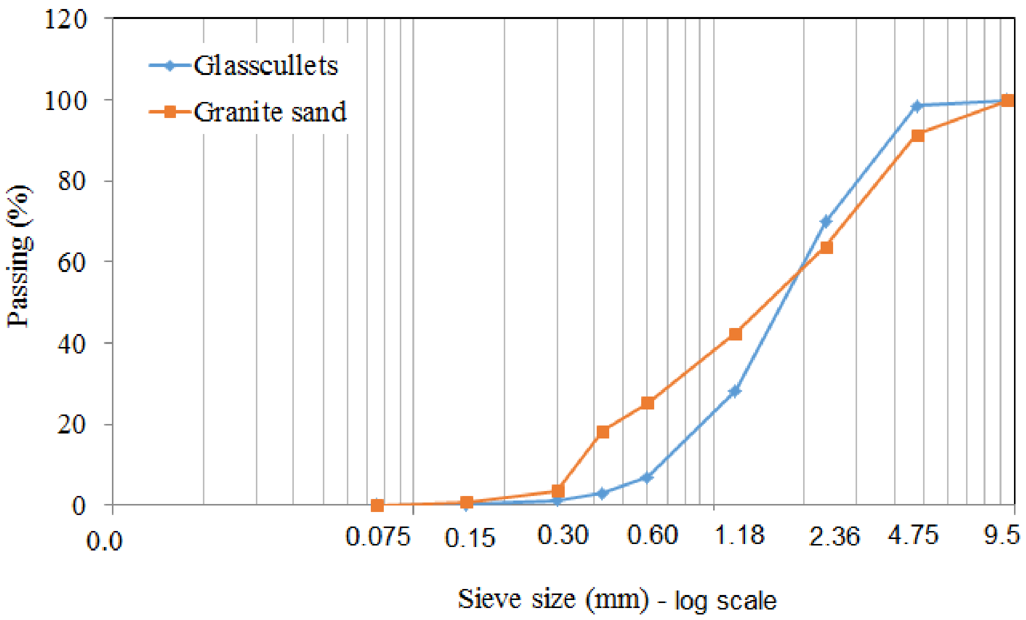
FIGURES

List of Figures:

***Fig. 1**– Glass cullets before washing (left) and after washing (right)*



[1 mm = 0.03937 in.]

Fig. 2*– Particle size distribution of glass cullets and crushed granite sand*

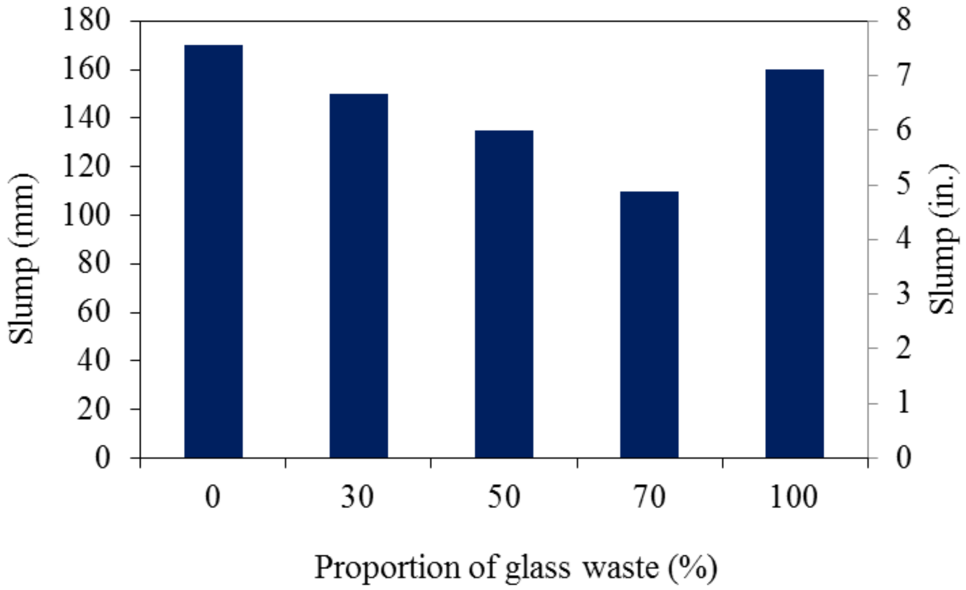


Fig. 3*–Workability of concrete containing glass cullets*

***Fig. 4**–Slump test of concrete for control (left) and 70% glass (right)*

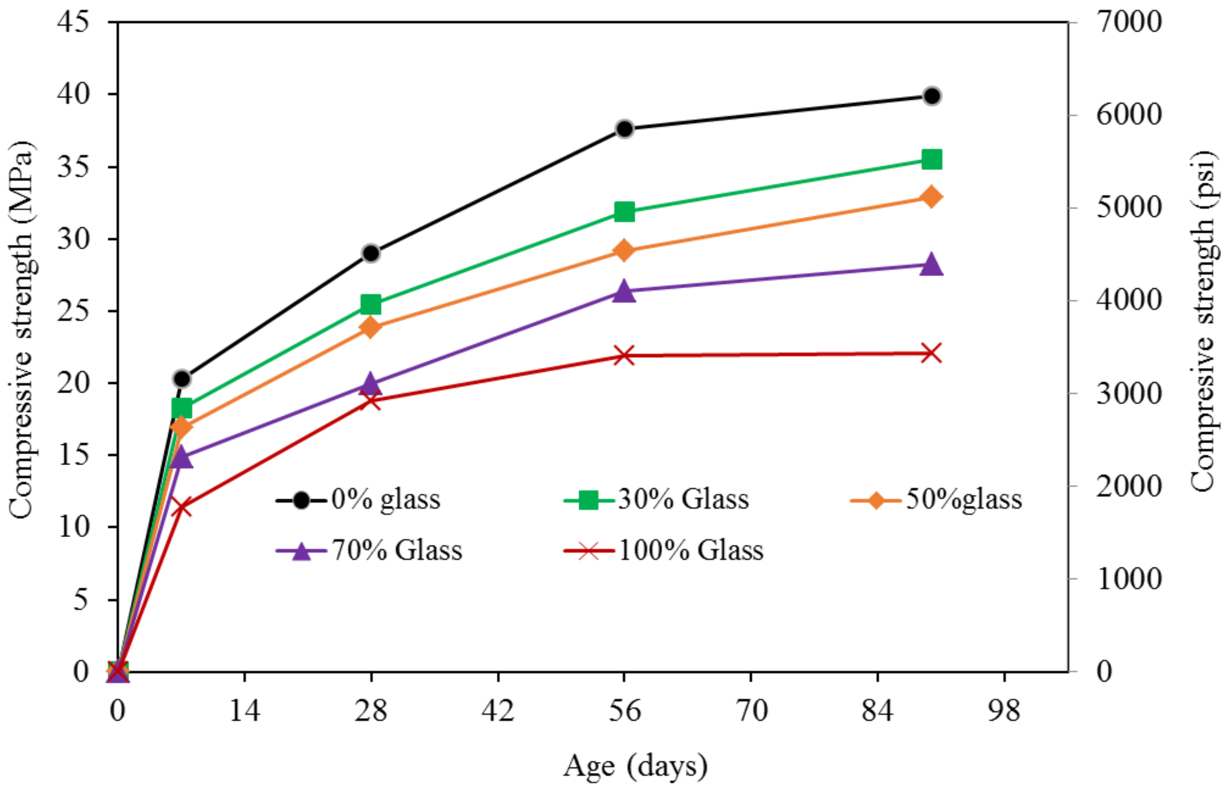


***Fig. 5**–Compressive strength of concrete containing glass*

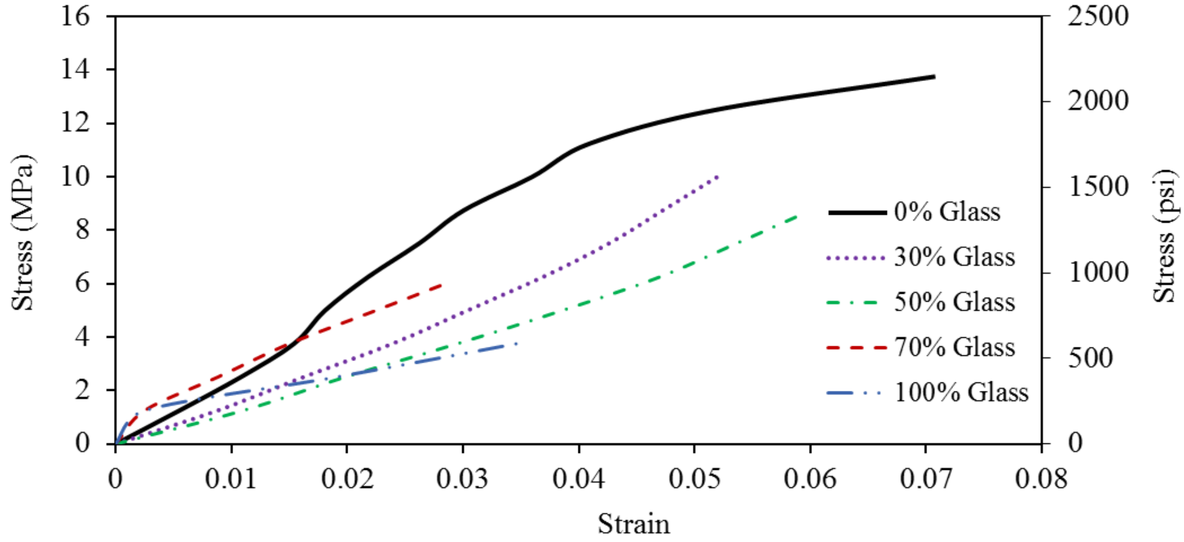


Fig. 6–*Stress-strain graphs of concrete containing glass*

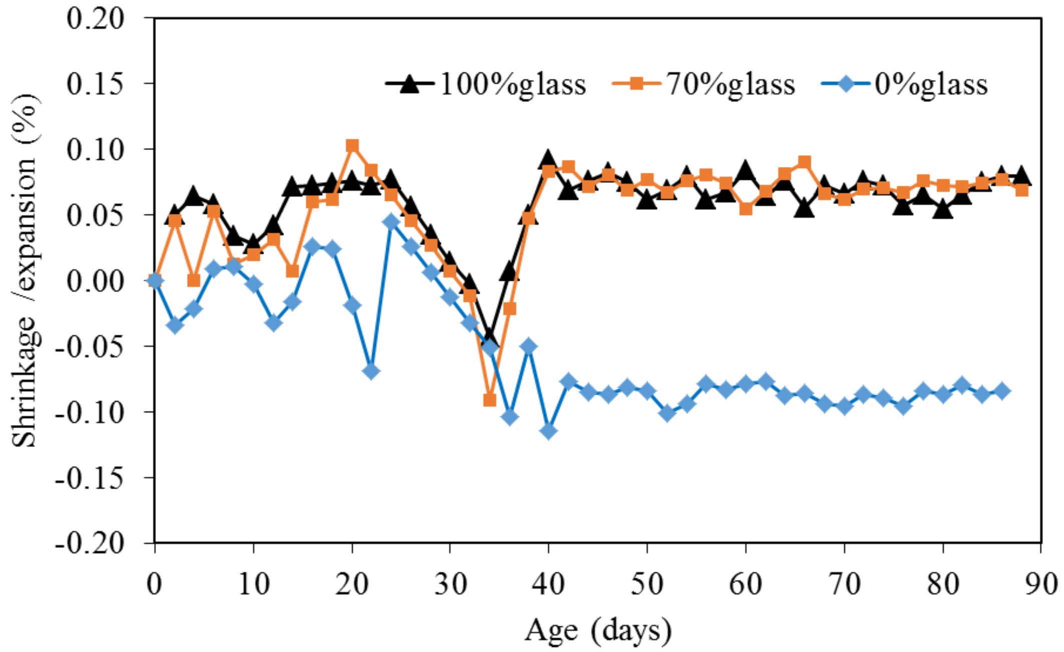


Fig. 7–*Shrinkage of concretes containing glass*