Use of Waste Window Glass as Substitute of Natural Sand in Concrete Production

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Abstract. Nowadays, the use of various waste and recycled materials and by-products is very common in construction. Several recycled materials are used in concrete in different ways and for various purposes. Basically, embedding any waste materials in concrete has two major objectives: reducing the environmental impact of concrete industry and eventually, enhancing some properties of the produced concrete. Glass is a non-biodegradable material and if not recovered and properly recycled, could negatively affect the environment. Cement-based materials offer an opportunity to valorize this type of waste materials in concrete when properly designed. Waste glass from window applications was collected from local workshop, screened and crushed into fine aggregate to be used as a sand substitute in concrete. This research aims to investigate the effect of using this recycled glass as fine aggregate replacement in concrete both at fresh and hardened states. Natural sand was replaced at 10%, 20% and 30% with the crushed window waste glass. Compressive strength of the designed glass-concrete was examined at 1, 3, 7 and 28 days while flexural and splitting tensile strengths were examined at 28 days of wet curing.

I. Introduction

The amount of waste materials generated by various industrial sectors is permanently increasing and causing a huge environmental problem. It has been agreed that re-using waste and recycled materials is the best available way to reduce the amount of solid wastes that may end up in disposal sites with all the disastrous environmental consequences and economical loss generated. Glass, with all its varieties, is one of these waste product that is classified as a non-biodegradable material and has substantial environmental impact. Park et al. (2004) [1] concluded that the majority of waste glass is not being recycled but rather abandoned, and is therefore the cause of certain serious environmental problems.

Over the last decades, several types of waste aggregates such as recycled concrete aggregate (RCA), ceramic tiles, red bricks, and waste glass, rubber tires and many other solid waste materials have been used as a partial or full replacement of natural aggregate in concrete production [2]. Recent researches have proved that RG can replace up to 20% of natural aggregates with an appropriate mechanical properties of concrete [3]. The predominant shape of glass grain when crushed is angular regardless of color of the waste glasses which could severely affects the workability concrete [4] and reduces its slump
and compacting factor [1,5]. Compressive, tensile and flexural strengths of concrete decreased when increasing the glass content [1,6] while a one year test period carried out by Taha and Nounu (2008) [3] showed no significant change in the compressive strength for concrete made with RG as compared to the control. Generally, it was concluded that in most cases, the glass do not significantly alter the durability-related properties of concrete [5].

The main objectives of this research project is to investigate the feasibility of using window waste flat glass in concrete mix at different replacement proportions. The key mechanical and properties of glass-concrete were examined.

2. Methodology and testing

2.1. Materials

Portland cement Type I with a specific gravity of 3.14 was used. Crushed limestone with a specific gravity of 2.8 and water absorption of 0.92% as combination of two aggregate fractions of 50% 10 and 50% 20 mm coarse aggregate. Natural sand used had a specific gravity of 2.71 and a water absorption of 3.71% while the crushed fine glass had a specific gravity of 2.49 and a water absorption of 0.06%. A polynaphthalene sulphonate-based superplasticizer (SP) was used at the appropriate dosage to achieve the targeted slump 60 ± 10 mm.

Table 1. Mix proportions for 1 m³ of concrete with a w/c = 0.48.

| Concrete Mixes                      | G0%  | G10% | G20% | G30% |
|-------------------------------------|------|------|------|------|
| Mix Content                         | Weight (kg) |      |      |      |
| Portland Cement                     | 375  | 375  | 375  | 375  |
| Water                               | 180  | 180  | 180  | 180  |
| Natural Coarse Aggregate            | 1150 | 1150 | 1150 | 1150 |
| Natural Fine Aggregate              | 731  | 658  | 585  | 512  |
| Crushed Recycled Waste Glass (Fine aggregate) | 0    | 73   | 146  | 219  |
| SP (ml)                             | 68   | 126  | 140  | 150  |

2.2. Testing procedures

Compressive strength was measured on cylindrical specimens having a size of 100 × 200 mm according to ASTM C39-12 standard test at 1, 3, 7, and 28 days of curing under wet conditions. The splitting tensile strength was tested at 28 days on cylindrical specimens of 150 × 300 mm as per ASTM C496-11 while flexural strength was conducted at 28 days on water-cured prismatic specimens of 100 × 100 × 500 mm as per ASTM C78-10. The cylindrical specimens tested on compression were capped before testing to ensure a uniform distribution of load. The load was applied at a constant rate of 2.0 kN/s, 2.5 kN/s and 3 kN/s for the compressive, flexural and splitting tensile strengths, respectively. Porosity and water absorption capacity of concrete mixes with and without glass aggregate were measured after 28 days of water curing on cubic samples of 100 mm sides as per ASTM C642-13.

2.3. Mix proportioning of concrete

Table 1 provides the mix proportions of concrete with and without fine glass aggregate. Three replacement levels of natural sand by recycled glass aggregate consisting of 10%, 20% and 30% were adopted. The w/c ratio of 0.48 and a slump value of 60 ± 10 mm were kept constant. Slump and compacting factor tests
were conducted after concrete mixing and thereafter, concrete specimens were cast, covered with plastic sheet and kept in laboratory for the first 24 hours. Specimens were demolded after 24 hours and cured in water tank till the time of testing.

Table 2. Fresh properties of concrete mixes.

|                  | G0% | G10% | G20% | G30% |
|------------------|-----|------|------|------|
| 15 min. Slump (mm) | 55  | 58   | 58   | 58   |
| 30 min. Slump (mm) | 35  | 36   | 37   | 35   |
| Compacting Factor | 0.917 | 0.945 | 0.946 | 0.949 |

3. Results and discussion

3.1. Fresh concrete

Slump and compacting factor (CF) test values obtained for the four mixes tested are given in Table 2. The results indicate a very similar slump values both after 15 min and 30 min of cement-water contact. The slump value after 30 min provide an indicator on the loss of slump when the mix is left to rest for 30 min after water-cement contact. This simulate the job site conditions where the concrete mix may not be used fully immediately after mixing. The inclusion of glass aggregate as a partial replacement of natural sand has induced a slight reduction in the slump values. To keep this parameter constant (constant w/c ratio and slump), an increase in the superplasticizer content is required. As shown in Table 1, an increase of around 100% in the amount of superplasticizer was required to keep the same slump when only 10% of natural sand was substituted by crushed waste glass aggregate. Increasing the replacement level of natural sand by the crushed glass aggregate required further increase of the superplasticizer content to keep the same slump value of $55 \pm 5$ mm.

The reduction in the slump values which is a measure of a decrease in the workability of concrete with glass aggregate is an indicator that glass aggregate had a negative impact on the workability of concrete. The higher the amount of glass aggregate embedded in the concrete matrix, the lower the workability of concrete. By using superplasticizer, it was possible to keep the same slump value for all concrete mixes with and without glass aggregate. On the other hand, the compacting factor values for glass concrete were higher than that of the control mix indicating a better compaction ability and less compaction effort needed compared to the control mix. In fact, the slump value and the required SP amount were adjusted before testing the concrete on compaction factor. The increase in the SP demand was proportional to the glass content added.

The main probable factors that could affect the workability of glass concrete are the angular and irregular shape of the glass aggregate, and their rough surface as compared to quite uniform and mostly spherical shape and smooth surface texture of the glass grains.

Furthermore, fresh density was measured immediately after mixing and the results are shown in figure 1. It could be seen that replacing part of the natural sand by the crushed glass aggregate did not exhibit any significant effect on the fresh density. Despite a lower specific gravity of the glass aggregate as compared to its corresponding natural sand, no major effect of the glass aggregate content was observed on the fresh density of glass concrete. This might be explained by the good compaction observed, as per the compacting factor values, for the concrete mixes containing glass aggregate.
3.2. Hardened concrete properties

3.2.1. Hardened density. Similarly, to the fresh density, the hardened density of concrete with and without glass aggregate was measured after 28 days of wet curing and the results are illustrated in figure 2. No significant differences could be observed between the hardened density of the control mix and the corresponding mixes with 10, 20 and 30% of glass aggregate incorporated as a partial replacement of natural sand. Although the glass aggregate has been found to have a lower density than the natural sand, the improvement in compaction of glass concrete, the reduction in the total volume of the pores and the filling action of the glass grains revealed by the compacting factor results contributed to enhance the overall hardened density of the glass concrete mixes.

No significant effect of the increase in the amount of glass aggregate in the concrete mix on the hardened density at 28 days was observed as could be seen in figure 2. However, a slight reduction could be noticed in the 28-day hardened density when the glass fine aggregate content in the mix increased from 10% to 20% and 30%. At 30% glass aggregate used as a partial replacement of natural sand, the 28-day hardened density is slightly lower than the control mix.

3.2.2 Compressive strength. Compressive strength was measured on cylindrical specimens 100 × 200 mm that were cured in wet conditions for 28 days. The results of the compressive strength development over time up to 28 days are illustrated in Figure 3. Except the mix G10%, the results showed no significant difference between the compressive strength of the control mix and concrete containing various replacement levels of glass aggregate both at early and later ages. The actual results indicate that glass aggregate could be used in a partial replacement of natural fine aggregate without or with very little negative impact on strength development. It could be speculated that the angular shape and the overall rough surface of the glass grains have contributed to this strength performance of glass concrete and favors a strong bonding properties between cement paste and the glass grains. In addition, fine particle of glass aggregate (passing 45 μm) may react with ortlandite produced by Portland cement hydration reaction via pozzolanic reaction and form a secondary C-S-H which further contributes to enhance the compressive strength of glass concrete. In fact, the formed secondary C-S-H will significantly reduce the
total porosity of the concrete and refine the pore network which enhances, mainly, the long term strength and durability performances of the glass concrete. This probable cementing and pozzolanic reaction between fine glass particles (mostly particles with size lower than 45 micron) is a long term reaction as the glass powder is known to react slowly over time. Glass, in terms of chemical composition has a high content of amorphous and reactive silica (around 70%) which could ensure a quite similar behavior to slag or other conventional pozzolanic materials such as fly ash.

![Figure 2. Hardened density of control and glass concrete.](image1.png)

![Figure 3. Compressive strength development over time for the control and glass concrete mixes.](image2.png)
3.2.3. **Flexural strength**: Flexural strength was measured after 28 days of wet curing on prisms measuring $100 \times 100 \times 500$ mm and the results obtained are shown in figure 4. It could be seen that a very minor reduction in the flexural strength has occurred as a result of a partial replacement of natural sand by the crushed waste glass aggregate. Also, no significant effect of the glass aggregate content on the flexural strength of concrete could be observed. The slight reduction in the flexural strength of concrete with glass aggregate could be explained by the weak bonding between the glass aggregate and the cement matrix. Although the fragments of waste glass have been crushed still the sides of glass grains could present a smooth side which contributes to weaken the bonding strength.

![Figure 4. Flexural strength of concretes with and without glass.](image)

![Figure 5. Splitting strength of concretes with and without glass](image)
3.2.4. **Splitting Tensile Strength.** Splitting tensile strength was measured at 28 days on cylindrical specimens measuring 150 × 300 mm and continuously cured under water. The results obtained are given in figures 5 and 6. Splitting tensile strength results are also correlated to the compressive strength results and shown in figure 6. It could be seen that no significant effect of the addition of crushed glass aggregate was observed on the splitting tensile strength at 28 days of water curing. Only a marginal reduction in the splitting tensile strength was noticed. This results support the compressive and flexural strengths data and re-assure that the glass used has no negative effect on the strength of the concrete even though a positive effect could be generated with more adjustment of grading and a proper proportioning of the mix.

![Figure 6. Relationship compressive strength-splitting strength of concretes with and without glass.](image)

3.2.5. **Permeable pore and water absorption.** Total volume of permeable pores and water absorption capacity of the control mix and concrete mixes designed with various glass aggregate contents were measured after being water cured for 28 days. Porosity results of concrete mixes is illustrated in figure 7. The results showed a very minor increase of the total volume of pores as the glass aggregate content in the concrete mix increases. This increase in the porosity might be attributed to the angular shape of glass aggregate grains. On the other hand, the effect of glass aggregate on the water absorption capacity is given in Figure 8. It could be seen that similarly to the porosity, water absorption capacity generally slightly increased as the glass aggregate content in the mix increases. A quite good correlation between the total permeable pores of concrete and the water absorption capacity was observed. The higher the porosity of the mix, the higher the water absorption capacity.

4. **Conclusions**

Based on the results of this study, the following conclusions can be drawn:

The physical properties of the crushed glass aggregate derived from the waste glasses are suitable as a fine aggregate for concrete production in terms of shape, size, gradation and specific gravity. The angular grain shape of crushed glass may affect the workability of concrete but was very advantageous for strength development.
Compressive, flexural and splitting tensile strengths have all shown an insignificant reduction due to the inclusion of fine glass as a partial substitute of natural sand. Porosity and water absorption of concrete with various contents of glass aggregate have slightly increased as compared to the control mix.

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Figure 7. Effect of glass aggregate content on the permeable pores of concrete.

Figure 8. Effect of glass aggregate content on water absorption of concrete.
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