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Production of High Strength Concrete by Partial Replacement of Fine Aggregates with Recycled Glass

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ABSTRACT

Concrete is undoubtedly the backbone of the construction industry. On the other hand, to produce concrete requires a considerable amount of natural resources so as to satisfy the demands on the market. This experimental paper investigated the effect of partially substituting fine aggregate with recycled glass to produce high strength concrete in order to alleviate the burden on the natural sources. A conventional high strength concrete was compared to different mixes containing glass aggregates as a replacement for fine aggregate at levels 10%, 25%, 50% and 75%. All the specimens were tested at 1-, 3-, 7-, 14- and 28-days air cured. Different types of tests were conducted and accurate data were collected and fully achieved and it can be noted that with increasing percentage of glass the compressive strength of concrete has a tendency to decrease. The maximum compressive strength for 10% and 75% were 48.81MPa and 32.11MPa respectively. The range of fresh density of glass concrete was found to be from 2237-1896 kg/m³.

Keywords: High Strength Concrete; Fine Aggregate; Glass Aggregate; Sustainable; Waste Materials

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PRODUCTION OF HIGH STRENGTH CONCRETE BY PARTIAL REPLACEMENT OF FINE AGGREGATES WITH RECYCLED GLASS

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Abstract

Concrete is undoubtedly the backbone of the construction industry. On the other hand, to produce concrete requires a considerable amount of natural resources so as to satisfy the demands on the market. This experimental paper investigated the effect of partially substituting fine aggregate with recycled glass to produce high strength concrete in order to alleviate the burden on the natural sources. A conventional high strength concrete was compared to different mixes containing glass aggregates as a replacement for fine aggregate at levels 10%, 25%, 50% and 75%. All the specimens were tested at 1-, 3-, 7-, 14- and 28-days air cured. Different types of tests were conducted and accurate data were collected and fully achieved and it can be noted that with increasing percentage of glass the compressive strength of concrete has a tendency to decrease. The maximum compressive strength for 10% and 75% were 48.81MPa and 32.11MPa respectively. The range of fresh density of glass concrete was found to be from 2237-1896 kg/m³.

Keywords: *High Strength Concrete, Fine Aggregate, Glass Aggregate, Sustainable, Waste Materials*

1. Introduction

Glass as a waste has become a main component of solid waste in many countries. In addition it can be in various forms for examples: windows containing flat glass, container glass, bulb glass and especially cathode ray tube glass. Right now, even if a small quantity of post-consumer glass has been reused and recycled, the remaining waste which amounts to 84% of the waste glass is sent to landfill. Being 100% recyclable material, glass possesses exceptional aesthetic properties and high performances which in turn make them suitable for many uses. Moreover, some studies suggest that the using glass as an aggregate in concrete can be very advantageous in the development of high quality concrete.

This research has four main goals that other students from different field of study can make reference that will provide them some aspects of using recycled bottles as a substitute for fine aggregate in concrete to

produce high strength concrete. In addition, this can trigger them to use other waste as an alternative to be used in construction material and raise awareness to the dangers with regard to the environment protection. Furthermore, developers and contractors can acquire information and knowledge resulting to the improvement in the method of construction by using alternatives than using fine aggregate in a concrete mix. Besides, regarding the aspect of innovating new ideas, non-government as well as government sectors can use new alternatives to exploit their resources for construction projects. Most importantly the purpose of this research will give a clear cut aspect of the feasible use of junk materials to be used as a construction material.

Several numbers of attempts have been made and were successful by using glass as an additive in concrete mix. Certain mix proposed among others has been successful in attaining some specific objectives.

2. Literature Review

The production of glass can be made in many various forms including container or packing glass, bulb glass and flat glass among others [1]. In the same line of thought, the use of glass products have taken great leap and as a result, an abrupt increase in waste glass. The production of glass from China and USA is approximated to be 32 and 20 Mt respectively while the EU countries producing around 33Mt of glass [2]. The United Nations, in 2004, estimated the total volume of solid waste to be 200 million tonnes of which 7% comprises of glass waste all over the world. As a matter of fact, in 2010, in the United States, the approximate value of waste glass was 4.6% of total MSW generation [3]. Besides, in Turkey this value amounts to 120,000 tonnes of which only 80,000 tonnes were recycled [4]. The Americans, in 2006, produced around 12 million tonnes of glass of which only 22% were recycled [5]. The waste glass generated daily in Hong Kong is approximated to be 373 tonnes per day in 2010 of which around 4500 tonnes were recycled per annum and in the same line, only 3.3% of it was recycled and the other 96.7% was sent to landfill for dumping [6].

From all these stated facts and figures, it came to the necessity to use these waste glasses in building materials. This literature contains a lot of previously performed papers relating the use of waste glass as a crucial component of building materials.

2.1 Workability

Metwally [7] has investigated waste glass performance in concrete mixes and as a

result he obtained a decrease on the workability. Taha and Nounu [8] used recycled glass as a substitute for fine aggregate with size less than 5 mm at levels 50% and 100% by volume and as a result he obtained a reduction in workability with an increase of glass content in the specimens. Park *et al.* [9] substituted fine aggregate with recycled glass of size 5 mm at levels 0%, 30%, 50% and 70% by weight in concrete mixes and reported that the compaction efficiency and slump decreases as the glass content of the samples increases. Castro and de Brito [10] reported a reduction in the workability of concrete mixes by replacing fine aggregate by waste glass aggregate with size less than 4mm at levels 5%, 10% and 20% by volume. In his research several w/c were used and the results of the workability showed a reduction in workability with increasing glass content. On the hand, Batayneh *et al.* [11] substituted sand by crushed glass at levels 0%, 5%, 10%, 15% and 20% keeping the w/c fixed and from the results he reported that the workability of the mixes was not affected by the inclusion of glass sand. Malik *et al.* [12] observed an increase in the workability with increasing glass content by the inclusion of glass sand to natural sand (size 1.18-0.075mm) at levels 10%, 20%, 30% and 40% by weight. Borhan [13] also reported an increase in workability with the substitution of natural sand to recycled glass (size 2.36-0.075mm) at levels 0%, 10%, 20%, 30%, 40% and 50% by volume. Terro [14] substituted natural sand with crushed bottle glass (size 4.75-0.075mm) at levels 0%, 10%, 25%, 50% and 100% by weight and reported the mixes containing glass had a higher workability than the control.

Table 1: Effect of glass sand on workability of concrete mixtures

Author	Glass content %	Glass size (mm)	Positive effect
Metwally[7]	-	-	x
Taha and Nounu[8]	50 and 100	<5	x
Park et al.[9]	30, 50 and 70	5	x
de Castro and de Brito[10]	5, 10 and 20	<4	x
Batayneh et al.[11]	5, 10, 15 and 20	BS 882:1992	No effect
Malik et al.[12]	10-40	1.18-0	✓
Borhan[13]	20, 40 and 60	3-0.5	✓
Terro[14]	10, 25, 50 and 100	4.75-0.075	✓

From the positive effects shown in Table 1, the researchers came out to the conclusion that waste glass sand can increase the workability due to the fact that of the poorer cohesion between smooth surface of cement paste and the glass sand (impermeable)[15]. In addition due to the lower absorption capacity [16] and the smooth surface of glass [17] are the foremost reasons of high workability. On the other hand, some studies reported a decrease in workability using glass sand as fine aggregate, this is so because of the sharp edges, angular shapes, harsh texture and also greater aspect ratio of glass sand that delay the bond of the glass particles and cement paste.

Ismail and Al-Hashmi [18] observed a decrease in fresh density of concrete mixtures by 1.26%, 1.96% and 2.26% with presence of 10%, 15% and 20% glass sand of size 4.75-0.15mm as a substitute for sand by weight. Batayneh *et al.* [19] also observed a decrease in fresh unit weight of concrete specimens containing glass sand. de Castro and de Brito [20] observed a decrease in fresh density of concrete mix containing glass sand. Borhan [21] observed a decrease in the fresh unit weight of concrete mixes containing glass sand. Taha and Nounu [8,22] reported a decrease in fresh density of concrete mixtures recycle glass sand. Table 2 below summarizes the effect of glass sand on fresh density of concrete.

2.2 Density

Table 2: Effect of glass sand on fresh density of concrete

Author	Glass content (%)	Glass size(mm)	Decreased fresh density
Ismail and Al-Hashmi[18]	15 and 20	4.75-0.15	✓
Batayneh et al.[19]	5, 10, 15 and 20	BS 882:1992	✓
de Castro and de Brito[20]	5, 10 and 20	<4	✓
Borhan[21]	20, 40 and 60	3-0.5	✓
Taha and Nounu[8,22]	50 and 100	<5mm	✓

2.3 Mechanical Strength of Concrete

Batayneh *et al.*[11] observed an increase in the compressive and splitting tensile strength of concrete mix containing waste glass at levels 5%, 10%, 15% and 20% by weight. Borhan [13] stated an increment of 15% ,for the 20% by weight recycled waste glass as a substitute for sand, in the 28 days splitting tensile strength. On the other side,

he also reported a reduction of 22% for the proportion of 60% of glass substitute for sand. Gatham *et al.*[19] observed an increase in the compressive strength with the substitution of waste glass at levels of 10% and 20% for sand. Park *et al.*[9] noticed a decrease with increasing glass content in mechanical properties at levels 0%, 30%, 50% and 70% by weight of concrete. Malik et al.[12] reported an

increase in the mechanical property of concrete with the inclusion of glass sand as a replacement for sand at levels 0%, 10%, 20% and 40%. On the other hand he reported that the proportion of 40% reduced the mechanical strength of the concrete. Taha and Nounu [8] noticed no big

difference in the mechanical strength of concrete with the inclusion of glass aggregate as a substitute for sand at levels 50% and 100% by volume. Table 3 below summarizes the effect of glass aggregate on the mechanical strength of concrete.

Table 3: Effect of glass aggregate on the mechanical strength of concrete

Author	Glass content (%)	Glass size (mm)	Positive effect
Batayneh et al.[11]	5, 10, 15 and 20	BS 882:1992	✓
Borhan [13]	20	3-0.15	✓ (age 28days)
	60	3-0.15	X (age 28days)
Gautam et al.[19]	10 and 20	4.75–0.15	✓
	30 and 40	4.75–0.15	x
Malik et al.[12]	10, 20 and 30	1.18–0	✓
	40	1.18–0	x
Park et al.[9]	30, 50 and 70	<5	x
Taha and Nounu[8]	50 and 100	<5	x

From the studies [8, 9, 11, 12, 19], the reduction in strength is directly related to the sharp edges and smooth surface of the glass in turn resulting in weak bonds being formed at the interfacial transition zone (ITZ) whereby glass bonds with cement paste matrix [23]. On the other hand the increase in strength can be explained due to the fact of glass particles' strength and surface texture compared to that of sand [11]. In addition, other study relates the increase of strength with the pozzolanic reaction of fine glass particles [21].

3. Research Methods

Within all the series of experiments conducted, the mechanical strength of concrete is one of the main objective in this paper whereby one among of the mix proportion used will achieve high strength property and can be used as a replacement for natural sand in concrete. Details of the experiments are given in the next sections.

3.1 Materials

1. Cement

Ordinary Portland cement (OPC) with specific gravity of 3.14 g/cm^3 was used.

2. Fine Aggregate (FA)

Local mine sand was used as fine aggregate with fineness modulus 2.7 and specific gravity of 2.7 g/m^3 and also its size and shape is beneficial in getting uniform particle size distribution in glass concrete. The glasses used were sieved and 1-5mm of glass particles also were used as fine aggregate replacement in the specimens for this study. Figure 1 below shows how the glass were collected and processed.

3. Coarse Aggregate (CA)

Crushed granite with maximum size of 20mm was used as coarse aggregate.

4. Other materials

Neutral (pH 7) potable water from the University's laboratory was used.

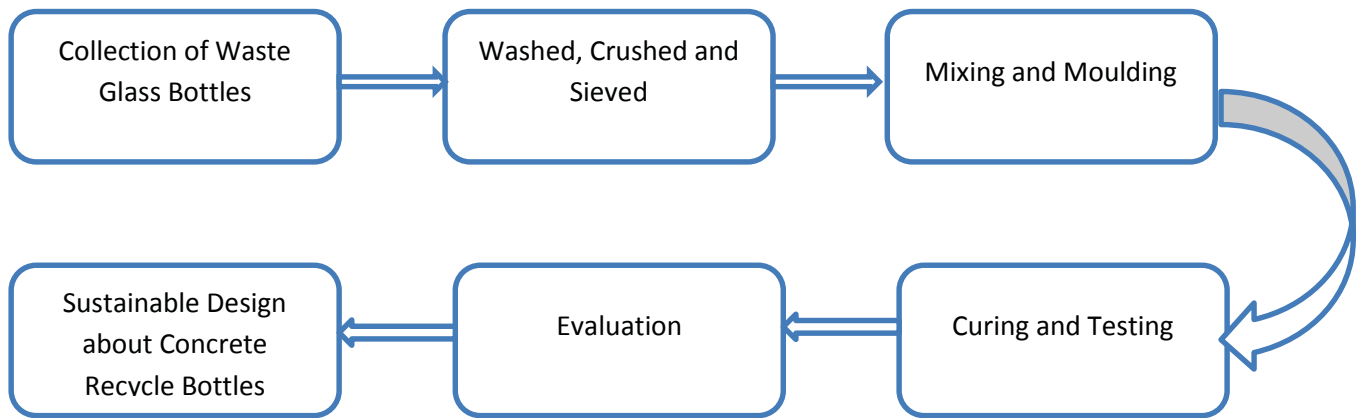


Figure 1. shows how the collection of glass was collected and processed

Details of the concrete mixes are shown in Table 4 whereby A1, A2, A3 and A4 mixes contain 10%, 25%, 50% and 75% of glass aggregate as a replacement for natural sand. The HSC mix represents the mix of grade 50 high strength concrete and also acted as a control for this research. The procedure for the mixing (hand batching) as follows: firstly, the glass will be mixed with sand in surface dry condition and mixed thoroughly for approximately 2-3 minutes. Coupled with that, cement will then be added to the mix followed by the addition of water. Finally the coarse aggregate will then be added. After 10 minutes of mixing the concrete, the latter is then poured in casting moulds into 3 layers and well compacted. After 24 hours, the specimen will be removed from the moulds without damaging the specimen and cured (Air Curing) before testing them. On the other hand, the high strength concrete will be prepared under same condition as described

above except there will not be any presence of glass in the mixture. In the same line of thought, the water content of both the glass high strength concrete and high strength concrete grade 50 will be kept constant. The specimens comprised of 150 mm cubes and 100mm diameter x 200 mm cylinders.

For the physical properties of glass such as specific gravity, aggregate impact value test and sieve analysis were recorded (BS EN 1097-6:1998; BS EN 1097-2:2010; BS EN 933-1; 2012) [25,26]. For the main tests performed, all tests were conducted using the following Eurocode Standards (BS EN 12350-2:2009, BS EN 12390-7:2009, BS EN 12390-3, BS EN 12390-6)[27,28,29]. The hardened concrete tests were carried at 1-, 3-, 7- and 28- days of air cured specimens. The tensile splitting tests were carried out at on 28-day air cured specimens.

Table 4: Design Mix Proportion of concrete

Mix Details	Ratio		
	Water/cement (w/c)	Sand/Cement (s/c)	Aggregate/cement (a/c)
A1	0.67	1.41	2.89
A2	0.67	1.41	2.89
A3	0.67	1.41	2.89
A4	0.67	1.41	2.89
H.S.C	0.67	2.00	4.00

4. Results and Discussion

4.1 Physical properties of Glass:

Figure 2 shows the distribution for the sizes of both glass and sand used as fine

aggregates in the mixes. From the figure, it can be deduced that the maximum size for glass was 2 mm as well as natural sand also having a maximum size of 2 mm.

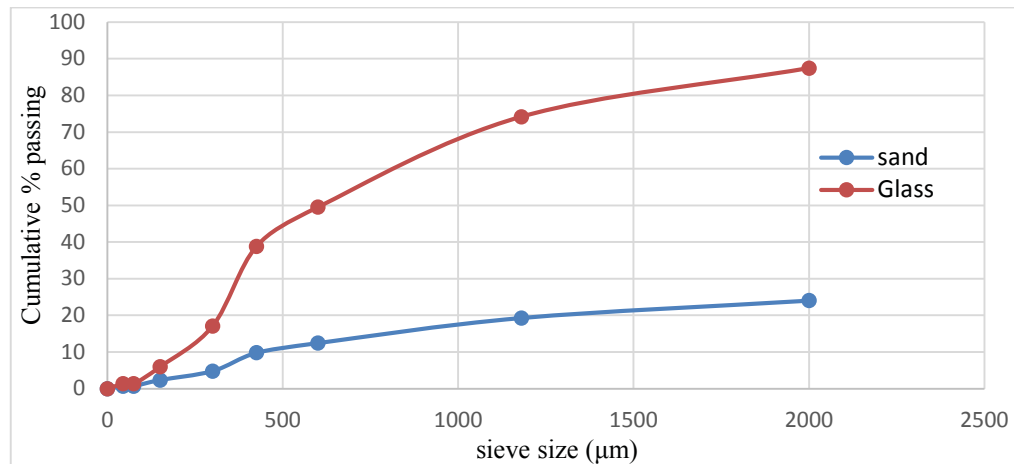


Figure 2. The particle distribution of fine aggregates

Table 5 compares the physical properties of waste glass and sand. The density of concrete with glass replacement was decreased due to the lower specific gravity of glass. This finding is considered

advantageous as it will decrease the dead weight of a building being constructed. The lower water absorption of glass justify high workability of concrete mix.

Table 5: The physical properties of waste glass and sand [30]

Physical property	Waste glass	Sand
Specific gravity	2.19	2.57
Density (kg/m ³)	1672	1688
Absorption (%)	0.39	2.71
Pozzolanic index (%)	80	-

4.2 Workability:

Table 6 shows the results for the slump tests performed for all mixes. Upon performing the mixing of the specimens, it was noticed that the batch A1 and A2 took around 5 minutes and it was easier to mix compared to the other mixes. In the same line of thought, the other specimens A3 and A4

took longer than 5 minutes (around 5-7 minutes) specially the A4 batch containing the most amount of glass content, 75%. It can be noted that mixing became lengthier with increasing amount of glass content. The mixing for the control (H.S.C) was within 5 minutes and achieved good consistency.

Table 6: Slump test results

Mix number	Glass replacement (%)	Mix proportion	Slump(mm)
A1	10	1:1.41:2.89	60-100
A2	25	1:1.41:2.89	80-120
A3	50	1:1.41:2.89	80-100
A4	75	1:1.41:2.89	100-150
HSC	-	1:2:4	60-140

4.3 Compressive strength

The compressive strength of mix A1 at an early stage was reported to be more or less same as that for the HSC. At a later stage it was observed that the compressive strength of mix A1 was more or less same as the HSC mix as shown in Fig. 3 below. The

remaining mixes A2, A3 and A4 with levels 25%, 50% and 75% respectively were reported to be lower than that of the HSC. The compressive strength of A1, A2, A3 and A4 were recorded to be as 48.81, 30.59, 25.11 and 20.29 MPa respectively at day-28. The compressive strength of the high strength

concrete mix was recorded to be 49.93 Mpa at day-28.

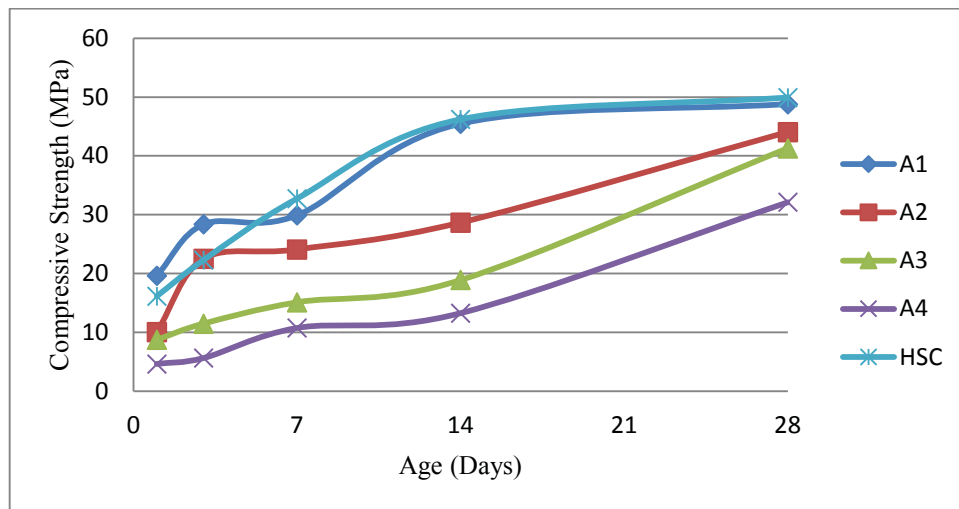


Figure 3. The compressive strength development of mixes

4.4 Density

The relationship between the densities and compressive strengths of the concrete specimens are shown in Fig. 4. It can be

deduced that as the proportion of glass aggregates increases, the density of the specimens decreases.

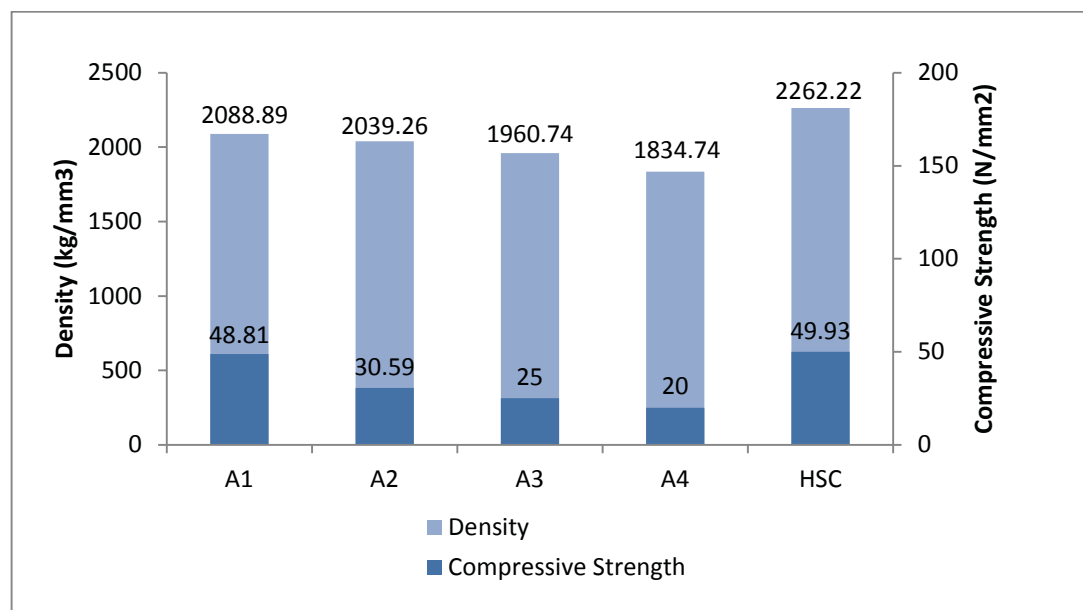


Figure 4: Relationship between densities and Compressive Strength

4.5 Conclusion

This paper, together with reviews from previous works, investigated the substitution of fine aggregate with waste glass at different levels in concrete. Hardened properties, fresh properties and durability of concrete mix containing waste glass aggregates also were studied. The

following conclusions can be summarized below:

- 1) High strength concrete grade 50 can be achieved with partial replacement of glass as fine aggregate.
- 2) The 10% glass replacement concrete has proved to have

compressive strength properties than other glass contents.

- 3) The 10% glass replacement specimens have more or less same compressive as the control does.
- 4) The use of glass as a substitute for fine aggregates decreases the water-cement ratio depending on the amount present in the mix.

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- 5) Making use of recycled bottled glass as substitute of fine aggregate may help reduce the material cost for concrete.

Acknowledgement

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