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RHEOLOGICAL AND MECHANICAL PROPERTIES OF RECYCLED WASTE GLASS CONCRETE AS PARTIAL REPLACEMENT OF FINE AGGREGATE

Md. Saeid Ebna Maleque*[1], Md. Mizanur Rahaman[2] and Md. Habibur Rahman Sobuz[3]

[1]Graduate Student, Department of Building Engineering and Construction Management, Khulna University of Engineering & Technology, Bangladesh, e-mail: ennamaleque.mdsaeid@gmail.com
[2]Graduate Student, Department of Building Engineering and Construction Management, Khulna University of Engineering & Technology, Bangladesh, e-mail: mrahaman495@gmail.com
[3]Assistant Professor, Department of Building Engineering and Construction Management, Khulna University of Engineering & Technology, Bangladesh, e-mail: habib@becm.kuet.ac.bd

***Corresponding Author**

ABSTRACT

The amount of used waste glass has been increased significantly in the last few decades. This high amount of unused waste glass could be a major problem for public health and the environment. This pullulating issue of waste glass can be solved by adopting a disposal system rather than simply dumping on landfills. To solve this problem, researchers in building construction technology conducted analytical studies highlighting the reuse of waste glass. As the waste glass is less expansive than other materials in concrete, especially fine aggregate, uses of crushed glass in concrete could be economical for construction, as well as, it would reduce the amount fo disposable wastes. Thus, the fundamental aim of this study is to investigate rheological properties and mechanical strengths of concrete replacing fine aggregate with 5%, 10%, 15%, and 20% of waste glass. In this study, the fine aggregate was replaced by locally available consumer by-product waste glass in different percentile and examined for 7 and 28 days curing period with a 0.45 water-cement ratio. As this paper is based on managing waste glass in the concrete industry to minimizing the cost, no extra chemical or admixture was used in this experiment. A series of standard tests such as slump test, compressive strength test, flexural strength test, splitting tensile strength test was conducted. The test results showed that slump value is decreased with increasing of waste glass percentage. Consequently, mechanical properties such as compressive, tensile and flexure strength were decreased with the increasing percentage of waste glass. For 5% replacement of waste glass, compressing strength decrease 8.06% and 6.57% respectively while for 20% compressing strength decreases up to 36.36% and 27.14% at 7 days and 28-day curing period while this decreasing rate increased with adding weight of waste glass. Tensile strength and flexure strength also show the same tendency of strength for 5% replacement where the strength decreases 9.6% and 31.79% respectively for 7 days curing periods and at a maximum 20% replacement in the fine aggregate the strength decreases 40.16% and 21.69% for 28 days curing period while compared with normal concrete. This decline in the strength could be caused by the adhesive strength between glass aggregate and cement paste as well as FM values of materials and compacting factors. Finally, from the results, it was concluded that there was a slight reduction on the mechanical strength as well as rheological properties of the concrete mix. This optimum percent of waste glass replacement in concrete not only help to reduce the environmental impact and landfill area but also produce sustainable and economic concrete.

Keywords: *Recycled waste glass, Glass aggregate, Compressive strength, Cement mortar, Waste management.*

1. INTRODUCTION

Humans are using glass for centuries. For its exceptional properties such as transparency, strength, durability, transmittance, people use it almost everywhere. In the building construction industry, different types of glass are used including, float glass, shatterproof glass, chromatic glass, tinted glass and each has a different application. Unfortunately, those glass has a limited life span and, in most cases, after using those glasses are dumped into the landfills. In the Republic of Korea, people use approximately 4.2 million tons of glass every year, which are typically used in building windows, bottles, etc. (Park, Lee, & Kim, 2004). Theoretically, glass is a 100% recyclable material; it can be indefinitely recycled without any loss of quality. Many developing countries are already recycling and reusing waste glass. The United States recycled about 2.99 million of tons' of common household glasses in 2014 (Gorospe, Booya, Ghaednia, & Das, 2019b). Moreover, reusing and recycling of waste glass in the construction industry could save our environment, saving landfill spaces and our precious natural resources (Rakshvir & Barai, 2006).

Different researchers performed various experiments to find out the reaction of waste glass in concrete mortar. Meyer, Egosi, and Andela (2001) depicted various methods and steps for collection, separation, grading to apply as aggregate in the concrete industry. Some findings showed that the type of glass and color of glass can impact the physical and mechanical properties of concrete when the waste glass is used as an aggregate (Gorospe, Booya, Ghaednia, & Das, 2019a; Topçu, Boğa, & Bilir, 2008). One of the problems of glass using in concrete is that it expands due to Alkali-Silica Reaction (ASR). To mitigate this problem, studies are conducted using natural and chemical admixtures such as fly ash, Li_2CO_3 (Topçu et al., 2008). There are few experiments are conducted to replace aggregate with waste glass. Topcu and Canbaz (2004) totally replaced traditional coarse aggregate with waste glass, whereas, Ismail and Al-Hashmi (2009) and Park et al. (2004) partially replaced fine aggregate with different colors of glasses. Additionally, other researchers used waste glass to replace aggregate on lightweight concrete, self-compacting concrete, masonry blocks etc. (Kou & Poon, 2009; Kralj, 2009; Palmquist, 2004).

In Bangladesh, most of the glass materials are thrown away after its first use in buildings and other packaging purposes. The idea of replacing fine aggregate i.e. sand with glass powder in the concrete mix will not only save landfill space but also mitigate the high demands of natural aggregate. By this means, it is possible to preserve our natural resources and cost, labor associated with shipping those raw materials. It will essentially reduce time and budget in a construction project.

2. METHODOLOGY

2.1 Materials

Type I Portland cement King Brand Cement (BDS EN 197-1:2003, CEM-I, 52.5 N. ASTM C-150, Type–I) was used in this investigation. For Coarse Aggregate, Brick chips (khoa) were used to prepare cylindrical specimens and short beam for flexure. The fineness modulus and average size of course aggregate is 7.61 and 9.5 mm to 12.5mm respectively. The maximum size of course aggregate is 25.4 mm. Local Sylhet sand was used as fine aggregate for all test specimens. The fineness modulus and average size of fine aggregate are 2.93 and 0.30 mm to 1.15 mm respectively. The maximum size of the fine aggregate is 4.75 mm. The fineness modulus of glass aggregate is 3.76.

Table 1: Approximate compositions and uses common forms of glass (Siam, 2011)

Type of Glass	Type of Glass	Usages
Soda-Lime-Silica	73% Silica-14% Soda-9% Lime-3.7% Magnesia-0.3% Alumina	Glass Widows, Bottles, Jars
Boro-Silicate	81% Silica-12% Boron Oxide-4% Soda – 3% Alumina	Pyrex Cookware, Laboratory Glassware
Lead (Crystal)	57% Silica-31% Lead Oxide-12% Potassium Oxide	Lead Crystal Tableware
Alumino-Silicate	64.5% Silica-24.5% Alumina-10.5% Magnesia-0.5% Soda	Fiberglass Insulation – Halogen Bulbs

2.2 Mix Design

The waste glass was replaced as fine aggregate as 0%, 5%, 10%, 15% and 20% in the concrete specimens. The ratio of cement, sand and brick chips was 1:2:3. And Cement water ratio was 0.45. Waste glass was crushed manually by using hammer and steel rods. First, coarse aggregate, fine aggregate, and cement with waste glasses were preliminary mixed and then sufficient water was used to the final mix. No admixture was used for this experiment. A hand mixture process was used to mixing the concrete. Different types of hand mixing tools were used, such as trowels, spades, tapping rods, buckets.

2.3 Sample Preparation

Cylinder moulds (100 x 200) mm were used to cast the specimens for compression and tensile test. For the flexure test, prism specimens (100 x 100 x 500 mm) were used. The proportions of materials were determined including cement, sand, aggregate, and water. All the materials were weighted by machine. The materials were mixed by handing batches with size of 25 percent greater than moulding test specimens. Then slump of each concrete batch was measured after blending according to standard code ASTM-C143/C143M-12. Figure 1 shows the materials of concrete for each batch. The moulds were placed horizontal surface and lubricated inside the surface with proper lubricant material. The green concrete was placed into the mould in three equal layers. Then, each layer was compacted uniformly, applying 25 stokes on each layer with a tamping rod that had a diameter of 16 mm. After finishing the top layer of the mould, a trowel was used to finish off the surface level with the top of the mould and stored in a room for hardening about 24 hours. After 24 hours the moulds were removed carefully so that no damage occurs of the specimens during unmoulding. The specimens were cured for 7 and 28 days. Plastic curing tanks were used to cure the specimens.

Figure 1: Sample preparation for concrete

2.4 Curing Period

The mixed loose concrete was moulded in the mould and given each specimen an identification number. Then the mould was kept for 24 hours for hardening at room temperature and 65% humidity environment. After this period of time, the concrete samples were demoulded and kept in water for curing. To conduct flexural, splitting tensile and compressive tests, half of each type specimens were cured for 7 days and other half of specimens were cured for 28 days. A rectangular tank with tap water was used for the curing of specimens. Before the test about 24 hours earlier the specimens were kept to dry for the test.

2.5 Test Methodology

2.5.1 Slump Test

The slump test was accomplished with a steel slump cone according to the ASTM-C143/C143M-12 test method. The slump cone was 30 cm in height, 10 cm in top diameter, and 20 cm in bottom diameter. The slump was measured for without mixing glass and with each percent of glass replacing fine aggregate with standard procedure.

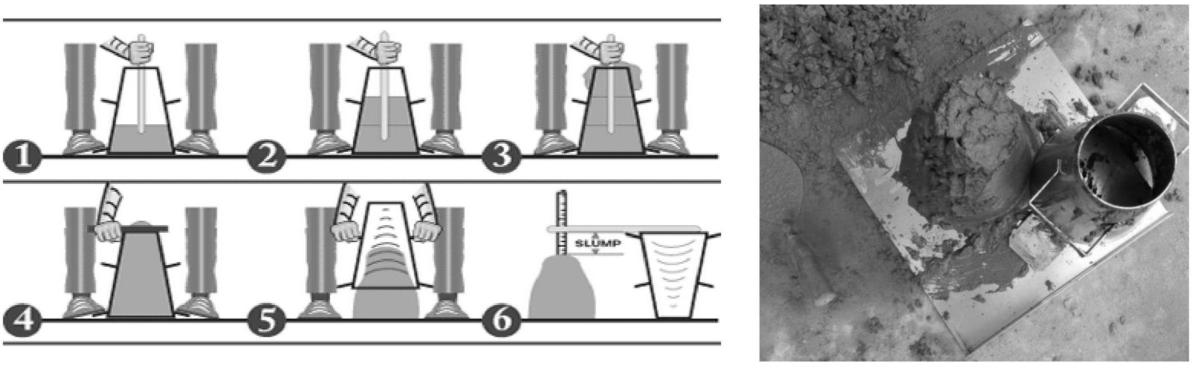


Figure 2: Concrete slump test procedure

2.5.2 Compressive Test

All cylinder specimens for compression tests were conducted according to the standard ASTMC39/C39M-12. All specimens were 100x200 mm in size cylinder to determine the compressive strength of waste glass concrete. The compressive strength of concrete specimens was investigated using a 3000kN digital compression testing machine which is shown in figure 3 and the load application rate was maintained 0.3 MPa/sec for all of the specimens tasted with the machine and applied until the concrete specimen fails.

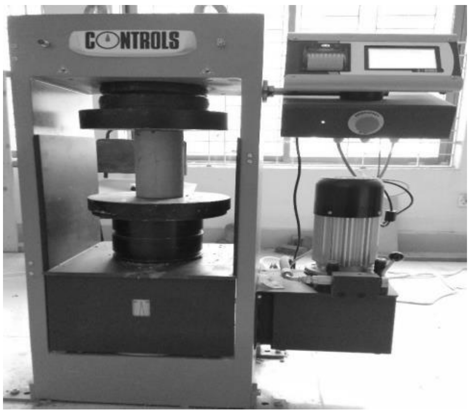


Figure 3: Digital Compression Testing Machine

2.5.3 Split Tensile Test

Standard ASTM C496/C 496M–04 test procedure adopted for testing splitting tensile strength. For splitting tensile tests, all the specimens were investigated with the same digital compressive the load rate was same as the compressive test.

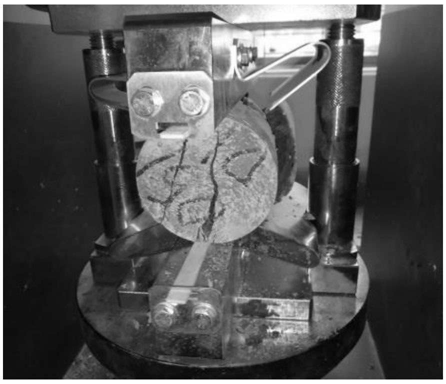


Figure 4: Splitting Tensile Testing Device with concrete mortar

2.5.4 Flexure Test

The flexural test was done according to ASTM-C78-02 which is known as the four-point loading method. A digital flexural testing machine of 200 KN was used to determine the flexural strength of specimens. The load application rate was maintained 0.3 MPa/sec for all of the specimens tasted with the machine. For 7 and 28 days cured simple beam specimens measuring 100x100x500 mm were used. Figure 5 shows the four-point loading method for testing flexural strength.

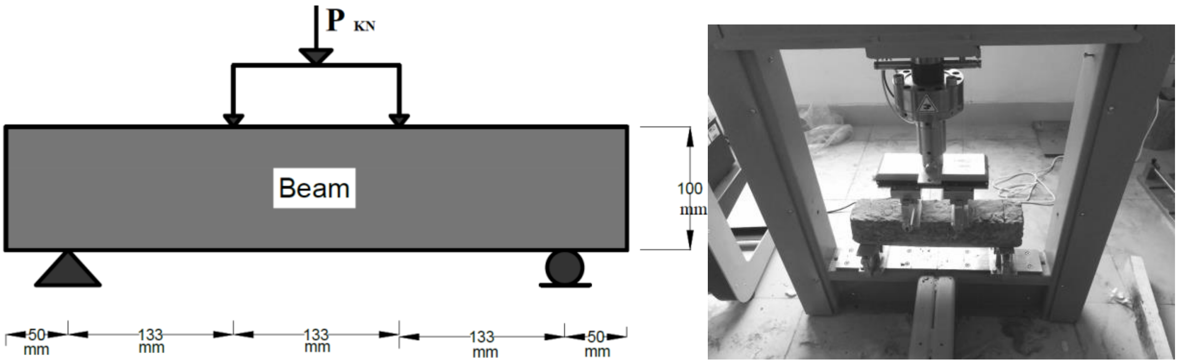


Figure 5: Digital flexure testing machine (four-point loading method)

3. RESULTS AND DISCUSSIONS

3.1 Effect of Glass Aggregate on Slump Value

The results showed that the slump value has a tendency to decrease with the increment of waste glass on the concrete mortar. This general tendency of the slump value is due to less fluidity of fresh concrete as glass aggregate had sharper and angular grain shapes and higher fineness modules than used sand. Additionally, with the increment of glass aggregate, more cement pastes got to attach on the outer layer of the glass, which caused less accessibility of cement paste for the fluidity of fresh concrete. It is noted that the slump values of 15% and 20% of waste glass mortar are same.

Table 1: Approximate compositions and uses common forms of glass

% of waste glass	0	5	10	15	20
Slump value (mm)	75.0	65.0	55.0	50.0	50.0

Figure 6 illustrates the decreasing ratio of glass aggregate on fresh concrete. For 5% waste glass it initially decreases by 13.33%. At 10% replacement decreasing rate it about 26.67%. For 15% and 20% replacement, decreasing rate is slightly low and it is 33.33%.

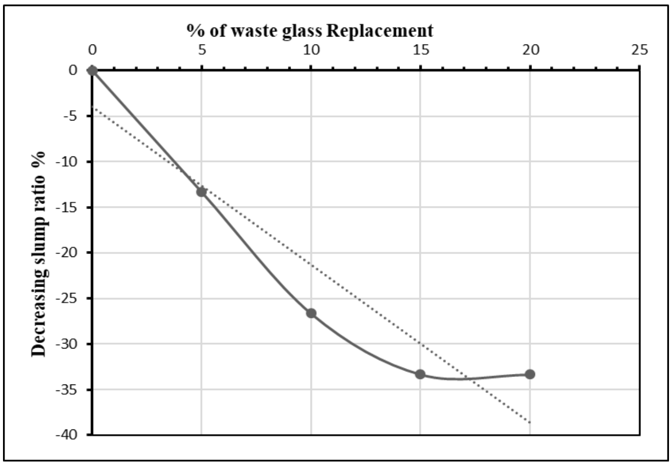
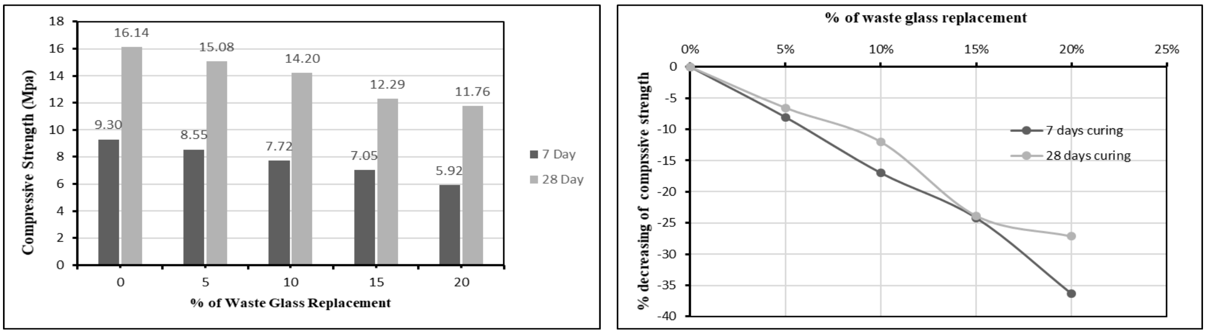


Figure 6: Decreasing ration of the slump.

3.2 Effect of Glass Aggregate on Compressive Strength

The result showed that the compressive strength of the concrete decreased when the percentage of waste glass increased. At 7 days of curing, decreasing rate of compressive strength is 8.06%, 16.99%, 24.19% and 36.36% for 5%, 10%, 15% and 20% of waste glass replacement from zero percent replacement concrete strength. It has the same impact on 28 days of curing. At 28 days this rate is 6.57%, 12.02%, 23.85% and 27.14% for 5%, 10%, 15% and 20% of waste glass replacement. This inclination is due to the decrease in adhesive strength between the surface of the waste glass aggregates and the cement paste as well as the increase in FM of the fine aggregates and the decrease in workability in accordance with the increase in the mixing ratio of the waste glasses, which is also observed in splitting tensile strength and flexural strength. Figure 7 (a) shows that the compressing strength with respect to the increasing percentage of waste glass on concrete for 7- and 28-days curing period.

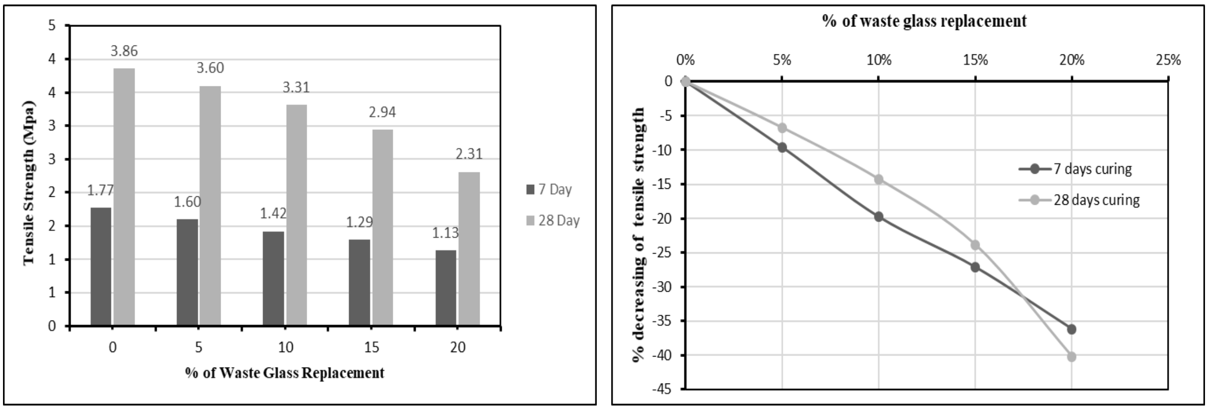


(a) (b)

Figure 7: (a) Test results of compressive strength; (b) Decreasing rate of compressive strength

3.3 Effect of Glass Aggregate on Splitting Tensile Strength

Test results in Figure 8 (a) indicate that the tensile strength of the concrete increased when percentage of waste glass decreased gradually. Figure 8 (b) represents that after increasing the percentage of waste glass content tensile strength of concrete decrease and this decrease rate for 7 days of curing are 9.6%, 19.77%, 27.12%, 36.16% for replacement of 5%, 10%, 15%, 20% of waste glass. Also, 28 days curing concretes show the same tendency of decreasing tensile strength which is slightly similar to one-week curing concrete. Decreasing rate for 28 days are 6.74%, 14.24%, 23.83%, 40.16% for replacement of 5%, 10%, 15%, and 20% of waste glass.

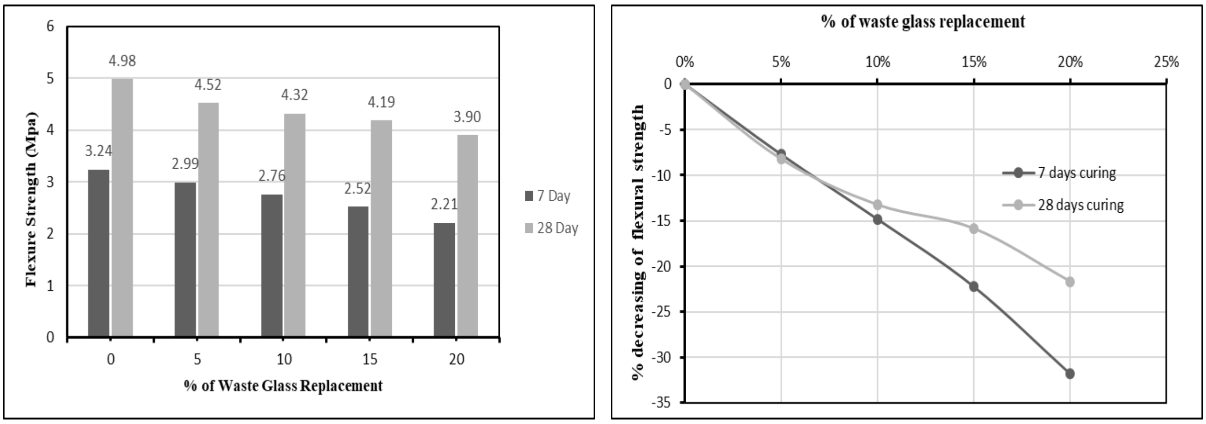


(a) (b)

Figure 8: (a) Test results of tensile strength; (b) Decreasing rate of tensile strength

3.4 Effect of Glass Aggregate on Flexural Strength

The curing period has a significant effect on concrete tensile strength. Figure 9 (a) illustrate the comparison between 7 days curing and 28 days curing for 0%, 5%, 10%, 15% and 20%. The decreasing rate of the tensile strength decreases uniformly for 5% and 10% replacement of waste glass on 7 days and 28 days curing period while for 15% and 20% replacement of waste glass shows lower decreasing rate in 28 days curing period compared to 7 days curing period shown in Figure 9 (b).



(a) (b)

Figure 9: (a) Test results of flexural strength; (b) Decreasing rate of flexural strength

4. CONCLUSIONS

The goal of this study is to investigate the properties of concrete containing glass as fine aggregate to reuse and recycle waste glass. The result showed that the slump value of concretes decreases with the increment of waste glass in concrete. The shape, size and angle of glass aggregate, attachment of cement paste on glass surface caused less fluidity for fresh concrete. Additionally, mechanical strength such as compressive strength, splitting tensile strength, flexural strength also decreases gradually with the percentile increment on the waste glass on concrete. FM value of aggregates, the adhesive bond between glass particles on fine aggregate and cement paste, compacting factor plays a vital role in decreasing mechanical strengths. Decreasing of strength from plain concrete for 5% replacement is lower than others. It was also observed that the decreasing rate for splitting tensile strength higher than compressive strength and flexural strength. The results show that waste glass could be used in concrete as well as in the construction industry. However, more studies should be conducted to gain optimum results using chemical properties and admixtures.

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