

Recycling of Glass Waste on the Concrete Properties as a Partial Binding Material Substitute

Fahmida Munim Ani, Md. Altaf Hossain, and Raha Nadoal Shahril

Abstract — Concrete is a significant construction material that is utilized extensively worldwide. A research study on the properties of concrete was conducted using Glass Waste (GW), which was readily available locally. As broken glass is difficult to sort, it is possible to positively utilize this waste particulate matter to reduce its detrimental impacts on both human health and the environment. Besides crushing or grinding, glass can transform into a natural pozzolan which enhances the fresh and hardened properties of concrete. This study also intends to reduce the amount of binding material used in the manufacturing of concrete blocks by making the best use of cement with Glass Waste. Therefore, an attempt has been made by using GW from 5-20% by weight as cement replacement for concrete blocks. When 5% crushed glass waste was added to the concrete mix (1:2:4), maximum compressive strength was 25.90 N/mm², as opposed to Ordinary Cement Concrete's 21.09 N/mm² strength, according to workability and laboratory testing. The 5% Glass Waste Mixed Cube and 5% Glass Waste Mixed Cylinder had the lowest water absorption test values at 2.22% and 3.58% respectively. In comparison to Ordinary Cement Concrete, Glass Waste Concrete has higher tensile strength. The maximum splitting tensile strength for 5% crushed Glass Waste Concrete was 2.115 N/mm², compared to 1.815 N/mm² for an Ordinary Cement Concrete Cylinder. The concrete with 20% glass waste content had the highest density, which was 2380.4 kg/m³ that defines good quality concrete.

Keywords — Compressive Strength, Density, Glass Waste Concrete, Splitting Tensile Strength, Water Absorption.

I. INTRODUCTION

Approximately 130 million tones (Mt) of glass are produced annually throughout the world [9]. The various flat glass products (construction and window glass, car glass etc.), account for 54 Mt or 42% of the total volume, tableware, which accounts for 5% of the total volume, container glass, accounts for 46% of the total volume and all other glass products, which accounts for the remaining 6% [9]. Only 21% of the world's glass production is represented by recycling, which is projected to be roughly 27 Mt [9]. With an estimated 32% recycling rate, container glass achieves the highest rates, while flat glass only recycles at a rate of 11% [9]. Though several countries attain recycling rates of above 90% for container glass which only equates to a recycling rate of less than 35% on a worldwide basis [9]. According to Alamgir and Ahsan [1], glass waste makes up 0.8% of the total municipal solid waste (MSW) created daily from Bangladesh's six largest cities, including Dhaka, Chittagong, Khulna,

Rajshahi, Barisal and Sylhet and Per Capita glass waste generation is 58 kg/day [1]. The majority of these wastes are dumped in landfills. These non-biodegradable abandoned materials are now posing a serious threat to the ecosystem. Glass wastes can be put to the concrete mixer as a binding substitute to the cement in powdered or crushed form.

Ordinary cement concrete has been gaining popularity in South-Asian countries due to its extended lifespan, cost-effectiveness, low environmental impact and versatility in various applications. Concrete has proven to be the most resilient and strong binding material in all environmental circumstances. For the duration of its service life, concrete is also intended to function efficiently with little maintenance. When waste glass powder was used in place of 20% of the cement, greater strength was obtained, and the peak percentage of the flexure strength increased by roughly 22% at this point [4]. According to research by Malik *et al.* [6], the amount of water absorbed reduced as the amount of waste glass content rose. In 28 days, the compressive strength of concrete made using 20% waste glass as fine aggregates increased by 25% and the density of concrete made with 40% waste glass decreased by 5%, making concrete naturally light in weight [6]. To enhance the mechanical and durability characteristics of concrete, cementitious ingredients such as pozzolans may be used. Very finely ground glass has pozzolanic qualities according to Meyer, Egosi and Andela [7] and can therefore be used as both a filler and a partial cement substitute [7]. Linear shrinkage and water absorption pose no problems because of the non-existing water absorption of glass [7]. Another advantage is excellent abrasion resistance due to the high hardness of glass [7].

II. MATERIALS AND METHODS

A. Materials Collection and Location

Glass wastes were collected from a number of building sites in Sylhet City as well as the regional glass producers in Bandar and the Kazir Bazar Area. These wastes came in a variety of shapes and sizes. The local construction market was used to obtain sand, cement and crushed stones.

B. Crushing

In order to prepare the materials, collected waste glass was first hand crushed with a mortar and pestle.

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TABLE I: MIXING PROPORTION OF GLASS WASTE CONCRETE CUBE

Sample	w/c ratio	Water (ml)	Cement (gm)	Glass Waste (gm)	Fine Aggregate (gm)	Coarse Aggregate (gm)	Slump (inch)
OCC (0%)	0.6	816	1360	0	2720	5440	8.0
G-1 (5%)	0.6	816	1292	68	2720	5440	7.7
G-2 (10%)	0.6	816	1224	136	2720	5440	7.3
G-3 (15%)	0.6	816	1156	204	2720	5440	6.8
G-4 (20%)	0.6	816	1088	272	2720	5440	6.2

TABLE II: MIXING PROPORTION OF GLASS WASTE CONCRETE CYLINDER

Sample	w/c ratio	Water (ml)	Cement (gm)	Glass Waste (gm)	Fine Aggregate (gm)	Coarse Aggregate (gm)
OCC (0%)	0.6	380	633	0	1266	2532
G-5 (5%)	0.6	380	601	32	1266	2532
G-6 (10%)	0.6	380	569	64	1266	2532
G-7 (15%)	0.6	380	538	95	1266	2532
G-8 (20%)	0.6	380	505	128	1266	2532

C. Sieve Analysis

Each time, a sample of crushed glass waste weighing 272 gm was taken and unwanted materials including pickets, stones, soil etc. were sieved out using a 4.75 mm mesh.

D. Mixing

The concrete mixture was manually prepared in the lab for use. In mixes, crushed glass waste was substituted for 5, 10, 15 and 20 percent by weight of cement. Crushed glass waste was combined in varied proportions (5%, 10%, 15% and 20%) with cement, sand and crushed stones at a ratio of 1:2:4 (M15) with a water-cement ratio of 0.6. The water-cement ratio must be carefully considered when mixing concrete because it influences the material's strength and workability. For ordinary cement concrete of grade M15, the typical w/c ratio is 0.6. Table I and Table II display the percentages of glass waste in the concrete mix.

E. Casting of Specimens

The test specimens were poured into steel cube-shaped (150 mm × 150mm × 150 mm) and cylinder-shaped (100 mm × 200 mm) molds. During casting, tamping rods were used to physically compress the cubes and cylinders.

F. Sun Drying

In order to make the concrete specimens harden enough to handle and prepare for the curing process, the specimens were removed from the molds after being sun dried outside for 24 hours.

G. Curing

To achieve the best strength and hardness for the further applications, concrete must be sufficiently cured. Over time, concrete hardens, initially setting, becoming firm and then strengthening in the weeks that follow. For concrete molds to become strong and fully harden, they need a humid, controlled environment. The concrete samples were cured in water tanks at a temperature of 28 ± 2 °C prior to testing.

H. Field Test on Fresh Concrete

a) Workability Test (Slump Test)

The workability of all concrete mixtures was assessed using the slump test utilizing a metallic slump mold with a bottom diameter of 20 cm (8 in), a top diameter of 10 cm (4 in) and a height of 30 cm (12 in). The level difference between the mold's highest point and the highest point of the

subsidied concrete was used to calculate the amount of slump.

I. Laboratory Tests on Hardened Concrete

a) Water Absorption Test

The proportion of water absorption was calculated for each concrete specimen and served as a rough indicator of durability. Five concrete cube OCC(0%), G-1(5%), G-2(10%), G-3(15%) and G-4(20%) specimens as well as five concrete cylinder OCC(0%), G-5(5%), G-6(10%), G-7(15%) and G-8(20%) specimens were utilized for the absorption test. The average dry weight of the cube and cylinder specimens was calculated after they were taken from the molds. The average weight of cube and cylinder specimens at 28 days old was calculated after curing in water that was approximately 28 ± 2 °C room temperature. Equation (1) was used to enter the values.

$$W = \frac{S_w - D_w}{D_w} \times 100 \quad (1)$$

where,

D_w = Dry wt. of specimen,

S_w = Submerged wt. of specimen.

b) Compressive Strength Test

The ELE compressive testing machine (Fig. 1) was employed at the Shahjalal University of Science and Technology materials testing laboratory to evaluate compressive strength.



Fig. 1. Compressive Strength Test of Glass Waste Concrete Cubes.

Four numbers of glass waste (5%, 10%, 15%, 20%) mixed concrete cubes and two numbers of ordinary cement concrete specimens were chosen to test compressive strength. Using (2), the compressive strength of the concrete sample was determined.

$$S = \frac{P}{A} \quad (2)$$

where,

S= Compressive strength, N/mm²,

P= Maximum applied load, N,

A= Cross-sectional area (Thickness × Width), mm².

c) Splitting Tensile Strength Test

Because it is difficult to assess tensile strength directly, therefore, a splitting tensile strength test can be used to assess tensile strength. Cylindrical specimens of 100 mm × 200 mm were formed for both ordinary cement concrete and glass waste concrete (GW were partially replaced with cement). This experiment makes use of the same tools as are used in compressive strength tests. Equation (3) was used to determine the splitting tensile strength of concrete specimens.

$$T = \frac{2P}{\pi LD} \quad (3)$$

where,

T= Splitting tensile strength, N/mm²,

P= Maximum applied load, N,

L= Length of the specimen, mm,

D= Diameter of the specimen, mm.

III. RESULTS AND DISCUSSION

A. Size and Structure

The cylinders and cubes had identical sizes and forms. Dry concrete cubes and cylinders had average length, width and height measurements of 150 mm × 150 mm × 150 mm and 100 mm × 200 mm, respectively. There were no flaws in the concrete surfaces. A few concrete samples created from glass waste that were used in various testing are shown in Fig. 2. When the sample was divided down the middle, there were no porosity, holes, or lumps in the inside of the concrete. The concrete's color was unaffected by the partial replacement of fine aggregate with waste glass [3].



Fig. 2. a) Glass Waste Concrete Cubes, and b) Cylinders.

B. Slump Test Result

Fig. 3 illustrates how the partial replacement of cement with crushed glass alters the workability of concrete as measured by the slump test. We observed that raising the glass waste content with W/C=0.6 reduced the slump of fresh concrete.

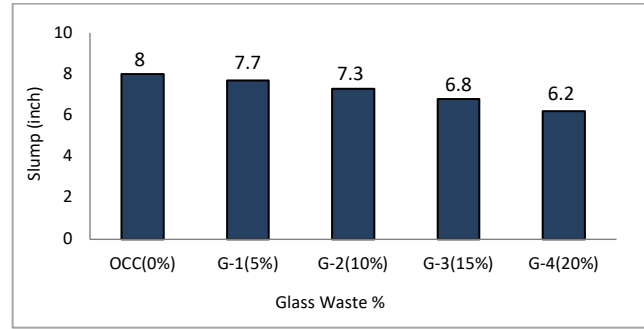


Fig. 3. Slump of Ordinary Cement Concrete and Glass Waste Concrete Cube.

While conducting a similar study for glass waste as partial replacement of cement also showed that workability of concrete decreases as percentage of glass powder increases [4].

C. Water Absorption

Concrete block void space affects water absorption. Fig. 4 shows the rates of water absorption between concrete cubes made of ordinary cement and those made from recycled glass. The absorption percentages are 2.22, 2.82, 3.42 and 4.02 for Crushed Glass Waste Cubes G-1(5%), G-2(10%), G-3(15%) and G-4(20%) respectively.

As a result, as more crushed glass is added to the concrete mixture, the percentage of water absorption slightly increases. It can be demonstrated that glass waste concrete cubes absorb more water than ordinary cement concrete cubes.

Similarly, Fig. 5 shows that the amount of water absorption significantly increases when the percentage of crushed glass in the concrete cylinder mix increases.

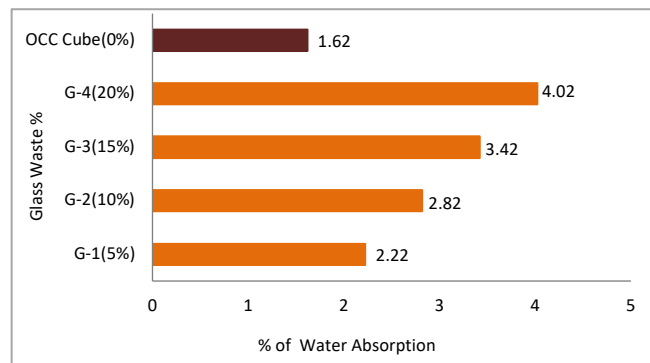


Fig. 4. Water Absorption of Glass Waste Concrete and Ordinary Cement Concrete Cube.

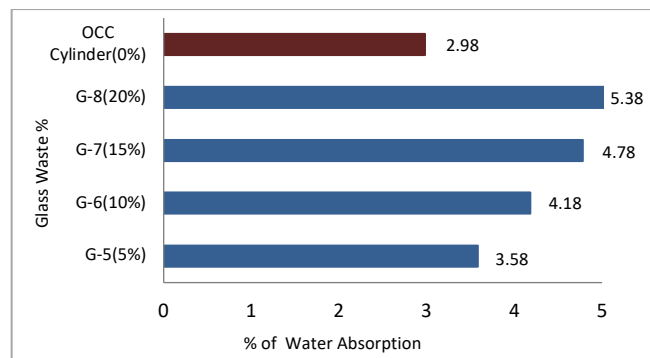


Fig. 5. Water Absorption of Glass Waste Concrete and Ordinary Cement Concrete Cylinder.

The absorption percentages for the Glass Waste cylinder sample G-5(5%), G-6(10%), G-7(15%) and G-8(20%) are respectively, 3.58, 4.18, 4.78 and 5.38. At 28 days, absorption results showed that absorption percentages of glass waste concrete cylinders were higher than ordinary cement concrete cylinders.

D. Compressive Strength

Fig. 6. depicts the compressive strength curve for concrete cubes constructed of ordinary cement and glass waste. Strength gradually decreases as the amount of glass waste in the concrete mixture increases. The compressive strengths of Crushed Glass Waste Concrete Cubes G-1(5%), G-2(10%), G-3(15%) and G-4(20%) are 25.90, 23.70, 21.50 and 20.30 N/mm² respectively. The highest measurement, 25.90 N/mm² contained 5% Glass Waste. In this case, the strength of the concrete cube produced of ordinary cement was 21.09 N/mm², above the level suggested for M15 Grade.

According to previous work, utilizing waste glass instead of fine aggregate in concrete mixes with a ratio of 1:1.67:3.33 and a water-cement ratio of 0.50 resulted in a modest increase in compressive strength at 28 days, reaching a level of 20% replacement. For 10% replacement, the highest strength was obtained 31.33 N/mm² [2].

E. Splitting Tensile Strength

Once again, as the percentage of glass waste increases, splitting tensile strength also reduces (Fig. 7). The splitting tensile strengths of concrete cylinders made from crushed glass waste, G-5(5%), G-6(10%), G-7(15%) and G-8(20%) are 2.115, 1.722, 1.553 and 1.005 N/mm² respectively. A concrete cylinder constructed of ordinary cement had a splitting tensile strength of 1.815 N/mm².

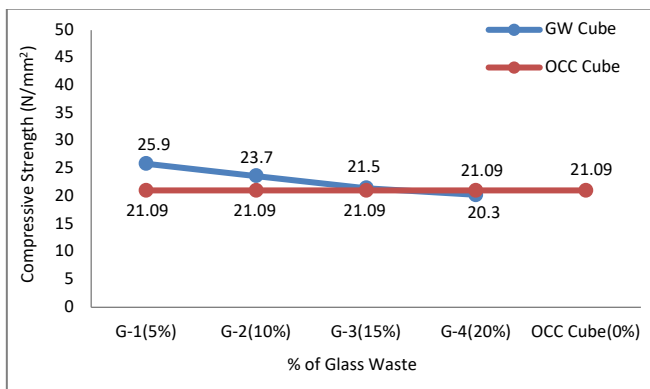


Fig. 6. Compressive Strength of Glass Waste Concrete and Ordinary Cement Concrete Cube.

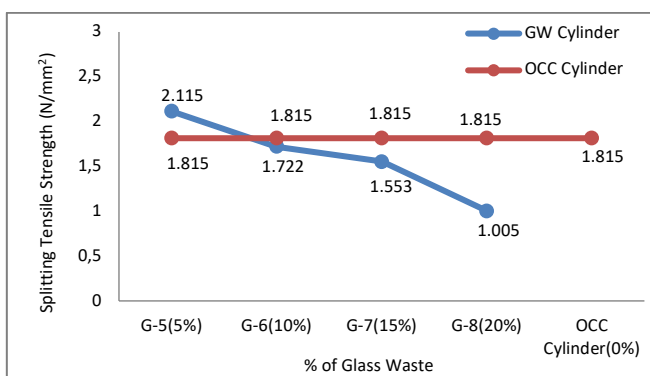


Fig. 7. Splitting Tensile Strength of Glass Waste Concrete and Ordinary Cement Concrete Cylinder.

With a 10% substitution of glass powder for fine aggregate in concrete samples cast in a ratio of 1:1.626:3.10, the highest split tensile strength was attained 3.88 N/mm² at 28 days [5].

F. Density

Fig. 8 displays the density curve for both the glass waste and ordinary cement concrete cubes. The densities of the Glass Waste Concrete Cube G-1(5%), G-2(10%), G-3(15%) and G-4(20%) are 2261, 2300.1, 2340.4, and 2380.4 kg/m³ respectively. A cube of ordinary cement concrete was evaluated and found to have a density of 2130.37 kg/m³. The 20% of glass waste that had the highest density was observed at 2380.4 kg/m³, which fulfills the specified 2400 kg/m³ for ordinary concrete. The majority of research showed that the density of concrete reduced with the addition of waste glass because of waste glass decreased density and specific gravity [8].

Lastly, Fig. 9 displays the density curve of a concrete cylinder made of ordinary cement and glass waste. Glass Waste Cylinder Concrete G-5(5%), G-6(10%), G-7(15%) and G-8(20%) have relative densities of 2305.2, 2325.6, 2345.9 and 2366.3 kg/m³. The density of ordinary cement concrete cylinders was measured at 2310.3 kg/m³.

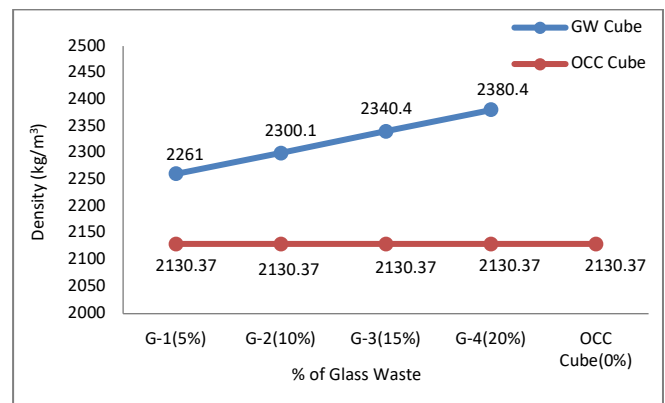


Fig. 8. Density Curve of Glass Waste Concrete and Ordinary Cement Concrete Cube.

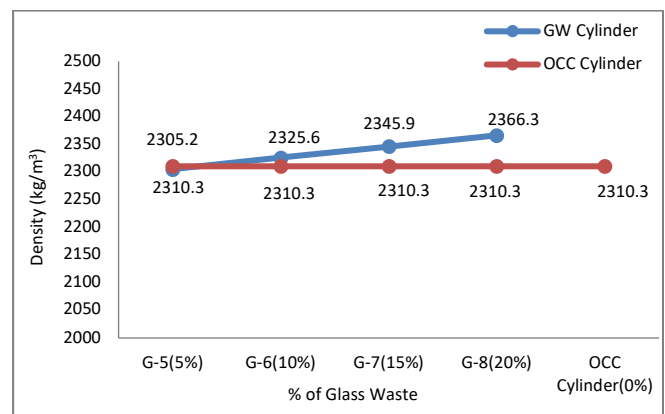


Fig. 9. Density Curve of Glass Waste Concrete and Ordinary Cement Concrete Cylinder.

IV. CONCLUSION

The findings of the experiment would support the following conclusions:

- i. As the amount of waste glass in the concrete mix increases, the slump value decreases.
- ii. The amount of water absorbed by glass waste mixed concrete was slightly higher than M15 Grade ordinary cement concrete. The concrete combined with G-2(5%) glass waste had the lowest water absorption, which was recorded 2.22%.
- iii. Glass waste concrete had significantly higher compressive strength than M15 Grade ordinary cement concrete. The concrete with G-1(5%) glass waste mixed in, had the maximum strength, which was measured 25.90 N/mm².
- iv. Concrete made from glass waste had a somewhat higher splitting tensile strength than concrete made from M15 Grade ordinary cement. The highest splitting tensile strength was measured 2.115 N/mm² with G-5(5%) glass waste mix.
- v. The densities of M15 Grade ordinary cement concrete and glass waste mixed concrete were quite equivalent. The concrete that included 20%(G-4) glass waste had the maximum density, which was recorded as 2380.4 kg/m³.

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CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest regarding the publication of this paper.

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- 1) MA Hossain, F Ishaque, GT Uddin, MAR Sarker, MH Rahman, IJ Ripa & J Baidya, (2020). Trend Analysis of Global Climate Model EdGCM Downscaled Data for Forecasting Boro Rice Yield in North-Eastern Region of Bangladesh. *Journal of Modeling Earth Systems and Environment, Springer Nature Switzerland AG.*

- 2) Ishaque, F., Ripa, I. J., Hossain, M. A., Sarker, M. A. R., Uddin, G. T., Rahman, M. H., & Baidya, J., (2020). Application of Transform Software for Downscaling Global Climate Model EdGCM Results in North-Eastern Bangladesh. *Journal of Environmental Engineering Research, Korean Society of Environmental Engineers* 26 (1): 190383.

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