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Durability Study of Glass Concrete

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***Abstract*— This paper has investigated the potential use of waste recycled glass in concrete as recycled glass sand. Crushed waste glasses accumulating in households around the world are an environmental concern, but also provide an available resource for potential use in concrete by partially replacement of fine natural aggregates. The objective of this study was to test the durability properties of concrete utilizing waste glasses as a partial replacement for fine natural aggregates. It is found that glass concrete (Glasscrete) mixture has greater resistance to chloride ion penetration than conventional natural sand concrete. As glasscretes are understood to have no internal porosity or little amount of porosity and no moisture absorption and there are smooth surfaces, creating a concrete volume that is more impermeable to ions and moisture than conventional natural sand concrete. Glasscrete absorbs about 8% less water than conventional concrete at same water-cement ratio. In addition, glasscrete mortars have 34% lower value of coefficient of thermal expansion than conventional natural sand mortar bar. Also, the greater elastic modulus of glasscrete mixture may contribute to a reduction in coefficient of thermal expansion. Finally, glasscrete mortars have lower shrinkage value than conventional natural sand mortar bar.**

Keywords—Durability of concrete, glasscrete, permeability, thermal expansion, drying shrinkage, water sorptivity

I. INTRODUCTION

This study is aimed to investigate and analyze the hardened properties of concrete by using recycled glasses as admixtures. Many studies have shown that huge amount of postconsumer glass i.e. bottles, windows etc. are generated throughout the world. The major portion of these postconsumer glasses are collected and transported to the recycling factories to recycle into new glass. But remaining massive amount of postconsumer glass is discarded along with other domestic solid waste into landfills. The primary reasons are the collection, transportation and recycling costs being high. If these postconsumer glasses could be incorporated fully or partially into modern concrete technology instead of fine aggregate, then economic concrete mix design may be possible and however generation of these kinds of household solid waste will be mitigated. The low porosity of glass also reduces chloride penetrability; therefore, glasscrete could be more resistant to chloride induced corrosion [1]. However, the work of [1] was solely performed on mortar mixtures and stopped at 45% of volume fraction of glass sand. Reference [2] also noted a reduction in the compressive strength with an increase in glass sand volume fraction. Flexural and tensile strength of mortars were found to reduce with increasing glass content. Reference [3] and [4] noted that the low porosity and absorption of glass sand reduce the drying shrinkage of concrete and its water absorption [5]. Overall, coarse glass aggregate was found not suitable for use in concrete. In contrast, tests showed promise for the use of fine glass aggregate in concrete [4] and [5]. Fine glass aggregates demonstrate shape characteristics similar to manufactured sand from natural rock, both being angular with an aspect ratio close to 1 [6]. Slumps results were generally comparable to natural sand mixtures [4] and [7]. The slump may remain the same, at lower dosages of plasticizer, for glasscrete when compared with natural sand concrete; this phenomenon may be the result of a weaker cohesion between glass and fresh cement paste and the smooth and impermeable surfaces of glass [4]. Glasscrete was also observed to retain adequate segregation resistance [4]. The use of waste glass as aggregate did not have a significant effect on the workability of concrete. But it decreases the slump, air content and fresh unit weight [7]. Concrete with glass aggregates should require a higher content of water than conventional aggregates to reach the same workability [7].

II. LABORATORY INVESTIGATION

Experimental outline include collection of material, preparation of specimen and laboratory testiing. There are some steps which were used to complete this research.

1. *Collection of Materials*

The glass material was collected from the local recycle material market and then crushed in the form like powder to use as the replacement of natural sand. Figure 1 shows the collection and crushing process of the glass materials. The natural sand was medium grain sand named as Sylhet sand, collected from the local construction market.

Fig.1: Collection and processing of recycled glass to make glass concrete.

2. *Materials Properties*

Locally available Sylhet sand and stone chip used as fine and coarse aggregate. Portland composite cement (PCC) has been used which contains clinker 65-79%, fly ash 21-35%, and gypsum 00-05%. The properties of the mentioned materials have been ensured by laboratory testing shown as Table 1.

Table 1: Summary of material properties

Properties	Coarse Aggregate	Natural sand (NS)	Glass sand (GS)	Combined NS+GS	Cement
Unit weight, kg/m^3	1567	-	-	-	-
Specific gravity	2.76	2.5	2.46	-	3.15
Fineness Modulus (F.M)	3.29	2.94	3.93	3.36	-

3. *Rapid Chloride Penetrability Test*

The ability of concrete to resist penetration from aggressive elements (i.e., chloride ions) is key to the durability of reinforcing steel in concrete. To evaluate the resistance of concrete against chloride penetration, this test was performed. The test method's cell diagram has been shown in following Fig. 2. Concrete cylinders were prepared and cut into 50mm thick disks from the center of the specimen. Subsequently, the specimens were loaded into two Plexiglas half cells and sealed using silicone rubber. Each half cell had a reservoir filled with a solution of 3.0% NaCl at negative side and 0.3N NaOH at positive side. The cells were subjected to a 60-volt DC voltage across the specimen's cross section. The voltage was applied for 6h, and average charge passed (Coulombs) was recorded every 30 min.

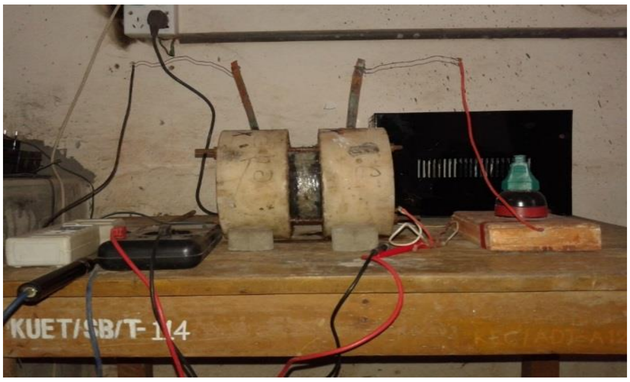

Fig.2: Experimental setup for penetrability test.

4. *Water Sorptivity Test*

For this test the cylinders were cut into 50mm thick disks as shown in Fig.3. The specimens were then conditioned in an environmental chamber at 50°C. After proper conditioning, the perimeter of the specimens was coated with vinyl electrician's tape to prevent air and moisture loss. Also, the top of the specimens was covered with a plastic sheet to prevent drying. Only the bottom face of the concrete was exposed to moisture.

Fig.3: Experimental setup for water sorptivity test.

Mass recordings of each specimen were then performed at certain time intervals to obtain the volumetric flux of absorbed water according to following equation:

$$I = \frac{m}{a*d} \qquad (1)$$

Where I = volumetric absorption flux (mm); m = change in specimen's mass (gm.) (i.e., mass of the absorbed water) as a function of time (t); a = exposed cross sectional area of the specimen (mm^2); d = $1mg/mm^3$ is the water density. The volumetric absorption flux is shown to be linearly related to the square root of time according to (Kelham 1988):

$$I(t)=St^{0.5} \qquad (2)$$

5. *Coefficient of Thermal Expansion (COTE) Test*

For this test mortar bars were cast to facilitate length measurements. Testing began after the specimens were moist cured for 14 days. The specimens were heated to a temperature of 80°C when fully submerged in 10.26P^H lime-water bath.

Fig.4: Preparation and submersion of sample into lime water bath.

After at least 16h at 80°C, the specimen's length was recorded. The specimens were then submerged back into the lime-water bath and cooled to a temperature of 60°C. After at least 16h at 60°C, the specimen's length was recorded. This temperature cycle (80-60°C and reverse) continued until specimens reached a constant length on cooling to 60°C. Once a constant length was achieved at 60°C, bar shrinkage caused and true COTE was obtained. The detail of testing has been mentioned in the following Fig. 4.

6. Drying Shriankage Test

Mortar bar were cast, demolded at 24h, and submerged in a 10.26 P^H lime-water bath for an additional 27 days. At age 28 days, the specimens were removed from lime-water bath and surface dried, their length was measured at certain time intervals.

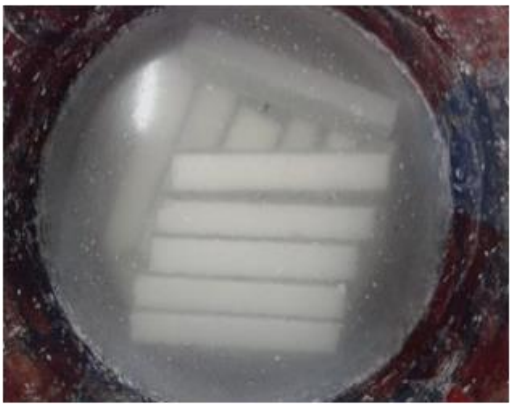

Fig.5: Submersion of mortar bar into lime water bath.

III. ITERPRETATION OF RESULTS

1. Rapid Chloride Penetrability of Concrete

Rapid chloride penetrability of natural sand concrete and glasscrete has given in the Table 2. In the same water-cement ratio, glasscrete mixture has greater resistance to chloride ion penetration than conventional natural sand concrete. As glasscretes are understood to have no internal porosity or little amount of porosity and no moisture absorption and there are smooth surfaces, creating a concrete volume that is more impermeable to ions and moisture than conventional natural sand concrete.

Table 2: Charge passed by the conventional concrete

Sl No.	Time (hr.)	Current I (amp)	Electrical charge (C)	Temperature at (-ve) cell	Temperature at (+ve) cell
1	0	0.09	0	22	21
2	0.5	0.08	180	23	22
3	1	0.09	432	24	23
4	1.5	0.10	702	25	24
5	2	0.11	936	26	24
6	2.5	0.11	1260	26	25
7	3	0.12	1620	27	26
8	3.5	0.12	2016	28	27
9	4	0.13	2304	28	27
10	4.5	0.13	2754	29	28
11	5	0.14	3240	30	29
12	5.5	0.14	3762	30	29
13	6	0.14	3024	31	30

Table 3: Charge passed by the glasscrete.

Sl No.	Time (hr.)	Current I (amp)	Electrical charge (C)	Temperature at (-ve) cell	Temperature at (+ve) cell
1	0	0.09	0	22	21
2	0.5	0.08	180	23	22
3	1	0.09	432	24	23
4	1.5	0.10	702	25	24
5	2	0.11	936	26	24
6	2.5	0.11	1260	26	25
7	3	0.12	1620	27	26
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13	6	0.14	3024	31	30

2. Water Sorptivity Of Concrete

Fig. 6 represents the result of initial sorptivity coefficient of conventional natural concrete and glasscrete at similar design strength and same-water cement ratio. The initial sorptivity of glasscrete is lower than conventional natural sand concrete. At same water-cement ratio, glasscrete has no or lower internal porosity than conventional natural concrete. Glasscrete has low capillary rise which result less moisture intake. Glasscrete also absorbs less water than conventional concrete at same water-cement ratio. Because glasscrete provides an impermeable volume in concrete, which makes it more difficult for water to penetrate into the concrete. Fig.6 shows that, mass of absorbed water decrease with the increase in time duration. Hence initial and final sorptivity value NS concrete is greater than GS concrete.

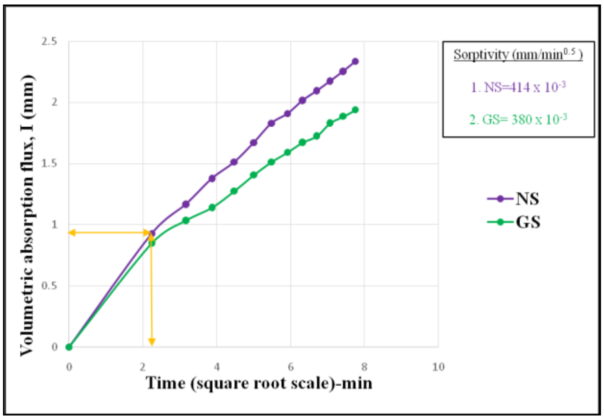

Fig.6: Water sorptivity of natural sand (NS) and glass sand (GS) concrete

3. Coefficient of Thermal Expansion of Mortar Bar

Coefficient of thermal expansion of natural sand and glass sand mortar bar are given in Table 4. Like most engineering materials, concrete has a positive coefficient of thermal expansion, but its value depends both on the composition of the mix and on its hygral state at the time of the temperature change. Table 4 represent that in the same water-cement ratio glasscrete mortars have lower value of coefficient of thermal expansion than conventional natural sand mortar bar. Additionally, the greater elastic modulus of glasscrete mixture may contribute to a reduction in coefficient of thermal expansion.

Table 4: Result coefficient of thermal expansion for NS & GS mortar bar

Parameters	0% G + 100% S	50% G + 50% S
Avg. change in length (cm)	0.05	0.03
Coefficient of thermal expansion ($10^{-4}/{}^0C$)	3.13	2.08

4. *Drying Shrinkage of Mortar Bar*

Fig. 7 shows that at similar design strength and same water-cement ratio glasscrete mortars have lower shrinkage value than conventional natural sand mortar bar.

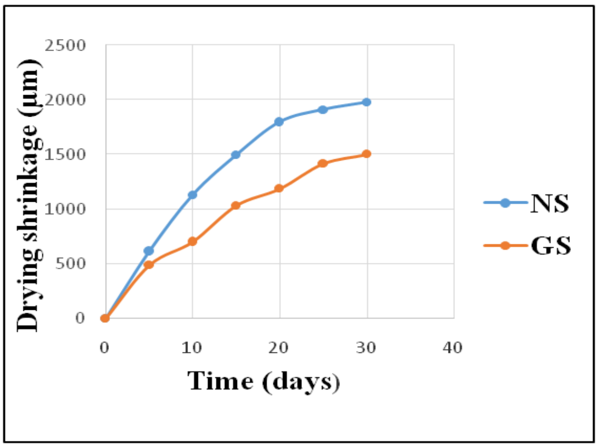

Fig.7: Ddrying shrinkage of natural sand(NS) and glass sand (GS) bar

IV. CONCLUSION

This study compares the performance of conventional natural sand concrete with concretes containing recycled glass sand. At a similar 28 days compressive strength, at 50% (50% G + 50% S) sand replacement no major differences have been found and in this mix proportion GS concrete exhibit, lower chloride ion penetration, lower water sorptivity, lower coefficient of thermal expansion and lower drying shrinkage than conventional NS concrete. These are the positive outcomes of this study incorporating recycled glass sand as 50% sand replacement.

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