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Investigation of Waste Glass as Partial Replacement of Fine Aggregate in Concrete at Reduced Water-Cement Ratio

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Abstract: *Solid waste management is one of the major environmental concerns worldwide. The presence and accumulation of this waste constitute environmental hazard and pose a risk to humanity. Therefore, using waste glass as fine aggregate replacement in concrete is an interesting possibility for economy on waste disposal sites and the conservation of natural resources. To deal with these problems, this study has been conducted to investigate the possibilities of using crushed waste glass as fine aggregate replacement in concrete. Five concretes mixes with 0%, 5%, 10%, 15%, and 20% replacement by weight of sand with waste glass were prepared. Experimental works were performed for a Grade 25 concrete to study the mechanical properties such as workability and compressive strength under different curing ages of 7, 14, and 28 days and the result showed that the mechanical properties of concrete can be improved as a higher compressive strength of concrete at 20% replacement of fine aggregate to the tune of 25.2% was obtained as compared with the control mix without waste glass for a 0.5 water-cement ratio and 22.7% was obtained as compared with the control mix without waste glass for a 0.45 water-cement ratio with a decreased slump. Thus, fine aggregate in concrete can be replaced with waste glass at a reduced water-cement ratio with mechanical properties at par with conventional concrete.*

Keywords: *Concrete, Glascrete, Density, Compressive strength, Workability, Water-cement ratio*

INTRODUCTION

Depletion of wealth resources can be reduced thereby reducing environmental risks by the production of non-conventional concrete. One of such ways is the use of glass which would otherwise be a waste material; as a constituent of concrete. Various researchers have found a way of replacing fine aggregate with a certain percentage of crushed waste glass. This study focuses on the use of waste glass as a partial replacement of fine aggregate in concrete as a way of determining a suitable percentage replacement that will give good mechanical properties at a reduced water-cement ratio. This practice has gained ground and that is called the glascrete; the use of glass in concrete production has become a popular concept in Concrete Technology. Waste glass is seen as an important solid waste found in various countries with little or no effect of weather conditions on it which makes it an environmental hazard in itself Caijun *et al.* (2007).

Water-cement ratio has proven to impact the mechanical properties of concrete particularly on workability and compressive strength, as reduced water-cement ratio projects increased strength, reduced permeability, increased resistance to weathering, reduced drying shrinkage, and cracking amongst others (National Concrete Pavement Technology Centre 2012). Glass has thus been seen to have a great effect on concrete both at plastic and hardened states; workability is increased, better strength, as well as freeze-thaw and surface resistance, is achieved.

While concrete is in its plastic phase, glass powder will increase its workability so less energy, cost, and time are required to place and consolidate the concrete. While the concrete is in its hardened phase, concrete containing glass powder exhibits better strength, freeze-thaw resistance, and sulphate resistance. Amongst others, the use of glass in concrete will help reduce the cost of waste disposal and consequently cost of concrete production; save a significant amount of energy, and reduces the amount of nitrogen dioxide, carbon dioxide, and other air pollutants emitted from the manufacturer cement clinker when ground glass powder is used as a replacement for fine aggregate. Glass has been seen to be a unique inert material, hard, brittle substance, that is usually transparent or translucent, made by fusing sand with soda and lime under a rapid cooling process. It could be recycled several times without changing its chemical properties. Environmental authorities have made consistent efforts to reduce, as far as possible, the disposal of post-consumer glass in landfills or recycle glass products. If glass could be incorporated into concrete production, it would greatly reduce the disposal of waste glass or its use in lower-valued works such as fill or road base materials (Shayan, 2002).

General Application of Waste Glass

In civil engineering, crushed waste glass has been mainly investigated as a substitute for sand and fine-grained aggregate in concrete production. In geotechnical engineering, for instance, the application of glass wastes is mainly limited to road pavements or as an additive to different soils for subgrade improvement. Glass cullet is recycled container glass (previously used for bottles, jars and other similar glass vessels) before processing. The material is typically collected through bottle banks, curbside collection schemes and from premises handling large quantities of containers. Crushed, graded glass cullet has been extensively investigated and tried in a number of construction and non-construction related applications (Meyer, 2001). Smith (2004) indicated that ground glass could be added to clay during the manufacturing of brick to save energy costs and produce bricks that are more resistant to frost damage and glass powder will serve as ―fluxing agent through the melting process leading to reduced melting temperature and period. The manufactured brick has also proved lower water absorption and higher compressive strength. Reindl (2003) reported that the glass cullet could be exploited in a variety of uses, including road construction aggregate, asphalt paving, concrete aggregate, building applications; fiber glass insulation, glassfiber, abrasive, art glass, landscaping, reflective beads, hydraulic cement and other applications.

Mechanical Properties of Glass Aggregate in Concrete

Many studies and attempts had been conducted in recent years to use crushed waste glass as a partial replacement for both coarse and fine aggregates. Such concretes have been seen to have good resistance to abrasion and lower shrinkage in the dry situation as compared with plain concrete. The concrete with waste glass has a lower water absorption ability compared with plain concrete (Concrete Technology Unit, 2003). The use of colored glass aggregate as a partial replacement of fine and coarse aggregates showed that the concrete with non-colored waste glass recorded a large expansion caused by Alkali-Silica Reaction (ASR) compared with concrete with colored waste glass Jin *et al.* (2000).

Meyer (2000) reported that the presence of glass as aggregate will affect the mechanical properties of concrete, due to the lower adhesion and bond strength between glass aggregate and cement paste, due to the relatively smooth surfaces of glass compared with relatively rough surfaces of natural aggregate. Metwally (2007) reported that the use of ground waste glass as aggregate in concrete will affect workability but had significant improvement of mechanical properties at later ages. Corinaldesi *et al.* (2005) showed that by using 30–70% of waste glass as a fine aggregate in concrete, no deleterious effect has been detected at a macroscopic level due to the reaction between cement paste and crushed waste glass with a particle size up to 100µm. A strong improvement in the mortar's mechanical performance was detected, due to the positive contribution of the waste glass to the microstructural properties. It was observed that no alkali-silica reaction (ASR) has been noticed with particle sizes up to 100µm, thus reflecting the feasibility of waste glass to be used as fine aggregate in mortars and concrete. Shayan (2006) opined that not more than 50% by weight of the normal aggregate could be replaced with a mixture of coarse and fine glass aggregate for structural and non-structural applications with appropriate precautions taken to minimize the detrimental effects of the alkali-silica reaction, such as using suitable pozzolanic materials in appropriate proportions. Mohamad (2005) reported that the compressive strength of concrete made with waste glass decreases up to 20% of its original value with increasing temperatures up to 700 °C. Concretes made with 10% aggregates replacement with fine waste glass had better properties in the fresh and hardened states at ambient and high temperatures than those with larger replacement. Concretes made with fine waste glass aggregates had higher compressive strengths than those made with coarse waste glass aggregate at ambient and elevated temperatures.

Alkali-Silica Reaction (ASR) in Concrete Glass

The ASR reaction is considered one of the adverse reactions in concrete occurring through the reaction between the type of active silica that reside in some types of aggregates and between the alkali that exists in cement. The reaction occurs between the hydroxide ions associated with the dissolved salts of sodium and potassium and the silica molecules of certain imperfectly crystallized siliceous rocks. Phillips *et al.* (1973) showed that up to 35% of glass cullet could be used in concrete in combination with low-alkali cement without detrimental effects. However, some specifying agencies indicated that the use of low-alkali cement does not guarantee that concrete containing reactive aggregates will not produce excessive expansion, i.e., increasing the cement content with low-alkali cement may increase the alkali concentration of the concrete pore solution and may cause deleterious expansion. The use of up to 30% glass aggregate in concrete might not cause deleterious effects, particularly if the alkali content of the concrete is below 3kg/m^3. Shayan (2006) and with fraction size equal to size 300µm, no expansion is observed (Meyer, 2000, Dhir et al., 2001, Reindl, 2003).

MATERIALS AND METHODS

The materials used for the study and the methods adopted include: Ordinary Portland Cement (Grade 42), sharp sand as fine aggregate, 19mm granite stones as coarse aggregate, potable water free from contaminants as specified by BS 3148 and crushed waste glass as partial replacement for fine aggregate were used in this research.

A. Mix Proportion and Curing

Five types of concrete mixes of Grade 25 were prepared using water-cement ratio of 0.5 and 0.45 each. The control concrete mixes, consisted of sand, gravel, cement and water.

The other mixes contained waste glass aggregates of 5%, 10%, 15%, and 20% by weight as a partial replacement of natural fine aggregate. Both types of concrete mixes were cured for 7, 14, and 28 days for each w/c. The molds were coated with engine oil to ensure that no water escaped during filling and to make removal of hardened concrete from mold easy. The mixing process was carried out manually using shovels. The materials were weighed using a weighing balance. The dry materials (cement, glass, coarse and fine aggregate) of each mixture were initially mixed until achieving a homogenous mix. Thereafter the quantity of water required was added to the dry mix.

B. Testing of Specimens

Two types of tests were conducted, i.e., fresh concrete and hardened concrete test.

C. Test on Fresh Concrete

The slump and unit weight tests were conducted on fresh concrete after the concrete mixing.

D. Slump Test

The objective of the slump test is to know the slump measurement for the degree of workability of the concrete after mixing. The workability was determined using the slump test as specified by BS 1881-108. A 300mm ruler, steel tamping rod, standard slump cone, flat metal base plate, small scoop and trowel were used in this test. The slump cone was greased and placed on the flat metal base plate which was placed on a smooth surface. The fresh concrete was poured into the slump cone in three layers. Each layer was tamped 25 times with the tamping rod. The test should be carried out by filling the slump cone in three equal layers with the mixture being tamped down 25 times for each layer. When the mold was filled with concrete, the top surface was leveled using a trowel. The mold was firmly held against its base during the entire experiment so that it does not move due to the pouring of concrete. Immediately after filling and leveling the concrete in the cone, the cone was slowly and carefully lifted vertically, an unsupported concrete then slumped. The decrease in the height of the centre of the slumped concrete is referred to as the slump. It was measured by placing the cone just beside the slumped concrete and the tamping rod was placed over the cone across the slumped concrete. The decrease in height of concrete as compared to that of the cone was noted.

E. Test on Hardened Concrete

The tests conducted for hardened concrete were destructive test; compressive strength test using a compressive strength testing machine.

F. Compressive Strength Test

The compressive strength test was carried out using cube specimens of size (150 x 150 x 150) mm using the compressive machine. The compressive strength test was carried out as per BS 1881-105. This test was carried out at the ages 7, 14 and 28 days. For each curing day, the cube was removed from the water and left to air dry for 24 hours. The dimension of the cube was taken to the nearest 0.2m after which the surface of the testing machine was cleaned. The cube was placed in the machine in such a manner that the load was applied to the opposite side of the cube cast. The cube was aligned centrally on the base plate of the machine and the movable portion was rotated gently by hand so that it touches the top surface of the cube. The load was applied gradually without shock and it continued at the rate of 140kg/cm^2/minute till the cube failed. The maximum load was recorded. The compressive strength of any mix was taken as the average of the strength of three specimens for each age.

RESULT AND DISCUSSION

The tests were carried out on fresh and hardened concrete. For the fresh concrete, slump test was conducted, while, for the hardened concrete, a destructive test; compressive strength test was carried out.

Test on Coarse Aggregate

The sieve analysis results of coarse aggregate are given in the Table-1

Table-1 Sieve analysis of 20mm coarse aggregate

Sieve size (mm)	Weight Retained (Kg)	Cum. Weight Retained (Kg)	% Passing by Weight
13.2	21.1	21.1	15.6
12.7	0.4	21.5	14
10.0	0.8	22.3	10.8
4.75	0.4	22.7	9.2
2.36	0.5	23.2	7.2

Test on Fine Aggregate

The sieve analysis results of fine aggregate are given in Table-2.

Table-2 Sieve analysis of fine aggregate

Sieve size (mm)	Weight Retained (g)	Cum. Weight Retained (g)	% Passing by Weight
4.75	0.7	0.7	99.8
2.36	8.0	8.7	97.1
1.18	20.6	29.3	90.2
0.60	108.2	137.5	54.2
0.21	106.9	244.4	18.5
0.15	17.4	261.8	12.7

Fineness modulus = $\frac{total\ \%\ retained}{100}$

Fineness modulus = 2.618

Test on Glass Aggregate

The sieve analysis results of glass aggregate are given in Table-3

Table-3 Sieve analysis of crushed glass

Sieve size (mm)	Weight Retained (g)	Cum. Weight Retained(g)	% Passing by Weight
4.75	53.2	53.2	82.3
2.36	121.1	174.3	41.9
1.18	44	218.3	27.2
0.60	37.4	255.7	14.8
0.21	25.2	280.9	6.4
0.15	10.9	291.8	2.7

Fineness modulus = 2.918

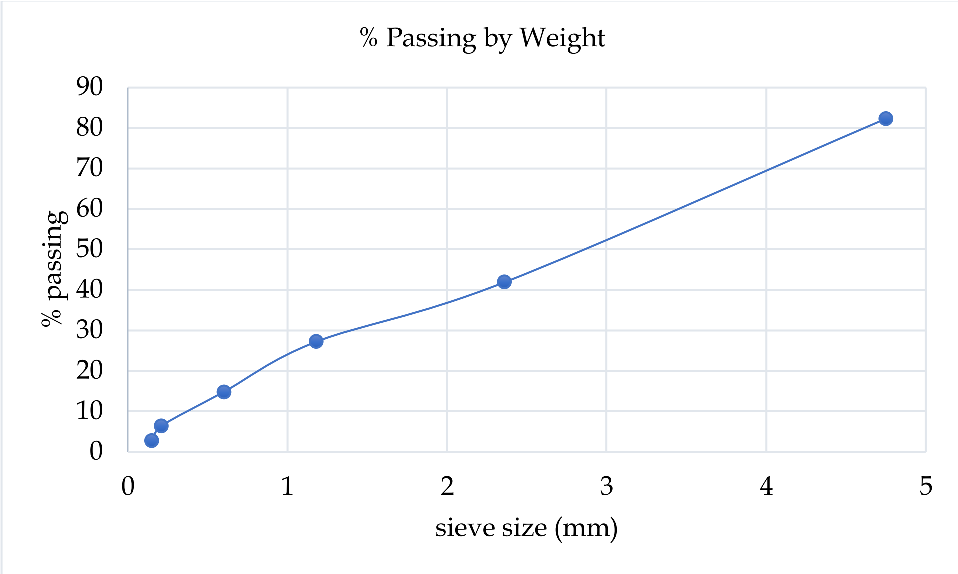

Fig. 1 Grading curve for glass aggregate

Mix Proportioning

The results for the five types of concrete mixes prepared for the two w/c are shown in Table-4

Table-4 Mix Proportions

No	Mix	Amount of Cement (Kg)	Coarse Aggregate (Kg)	Fine Aggregate (Kg)	Crushed Glass (Kg)
1	Control mix	7	28	14	0
2	5% Replacement	7	28	13.3	0.7
3	10% Replacement	7	28	12.6	1.4
4	15% Replacement	7	28	11.9	2.1
5	20% Replacement	7	28	11.2	2.8

Fresh Concrete Properties

Slump Test

The result of the slump test is illustrated in Table-5 and 6. It can be seen that the slump values slightly decreased as the waste glass ratio increased compared to the control mix for both cases. The maximum decrease for the 0.5% w/c was at 20% replacement where a 51% reduction in slump was observed and the minimum decrease of 10.2% was seen at 5% replacement as shown in Fig. 2. This could be inferred from previous studies, since waste glass aggregates had sharper and more angular grain shapes and were larger than sand, which resulted in less fluidity.

Table-5 Result of Slump Test at 0.5 water cement ratio

No	Mix	W/C	Slump (mm)
1	Control	0.5	49
2	5% Replacement	0.5	44
3	10% Replacement	0.5	30
4	15% Replacement	0.5	25
5	20% Replacement	0.5	24

Table-6 Result of Slump Test at 0.45 water cement ratio

No	Mix	W/C	Slump (mm)
1	Control	0.45	45
2	5% Replacement	0.45	40
3	10% Replacement	0.45	25
4	15% Replacement	0.45	20
5	20% Replacement	0.45	17

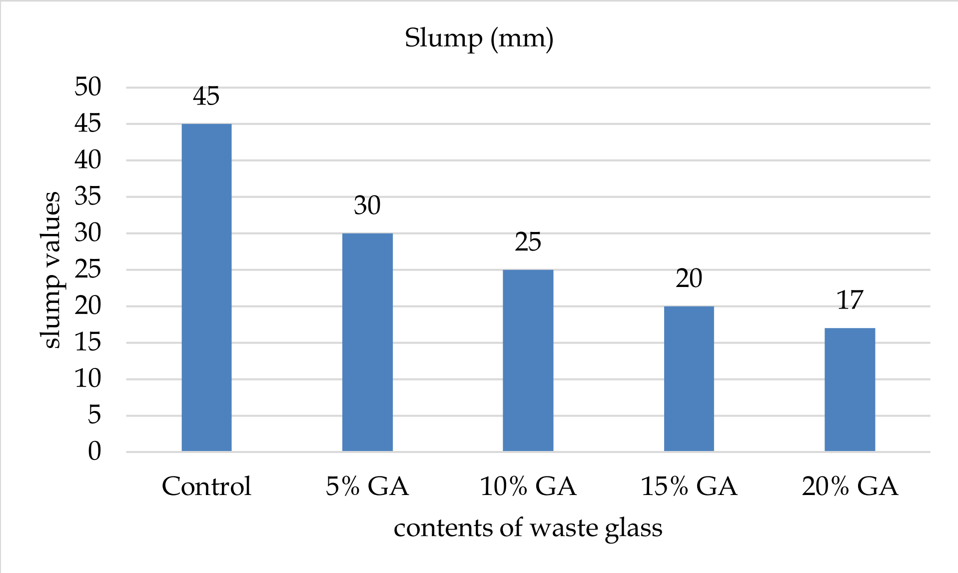

Fig. 2 Result of Slump Test at 0.45 w/c

Hardened Concrete Properties

Destructive Compressive Strength Test

The compressive strengths of the control and waste glass concrete mix at 7, 14, and 28 days are presented in Tables-7 and 8. The comparison between the values of the compressive strength for the various mixes is shown in Fig. 3. The development of compressive strength with time for the control mix and other mixes containing 5, 10, 15, and 20% of glass aggregate as partial replacements for the sand is shown in Fig. 4. All control and glass aggregate mixes show a continuous increase in strength with age for the two cases. It can be observed that the percentage increase in compressive strength with age is generally increased with the increment of glass aggregate replacements up to a tune of 25.2% at 20% replacement at 28 days for 0.5 w/c and 22.7% at 20% replacement at 28 days for 0.45 w/c. This compares favourably with works done by Tamanna *et al*. (2013).

Table-7 Compressive Strength of Concrete at 0.5 w/c

Mix	7 days	14 days	28 days
Control	22.6	25.6	26.2
5% Replacement	23.1	27.2	29.6
10% Replacement	24.3	27.8	31.4
15% Replacement	24.5	29.7	32.2
20% Replacement	25.1	29.6	32.8

Table-8 Compressive Strength of Concrete at 0.45 w/c

Mix	7 days	14 days	28 days
Control	22.6	25.6	28.2
5% Replacement	23.1	27.2	30.4
10% Replacement	24.3	27.8	32.1
15% Replacement	24.5	29.7	32.9
20% Replacement	25.1	29.6	34.6

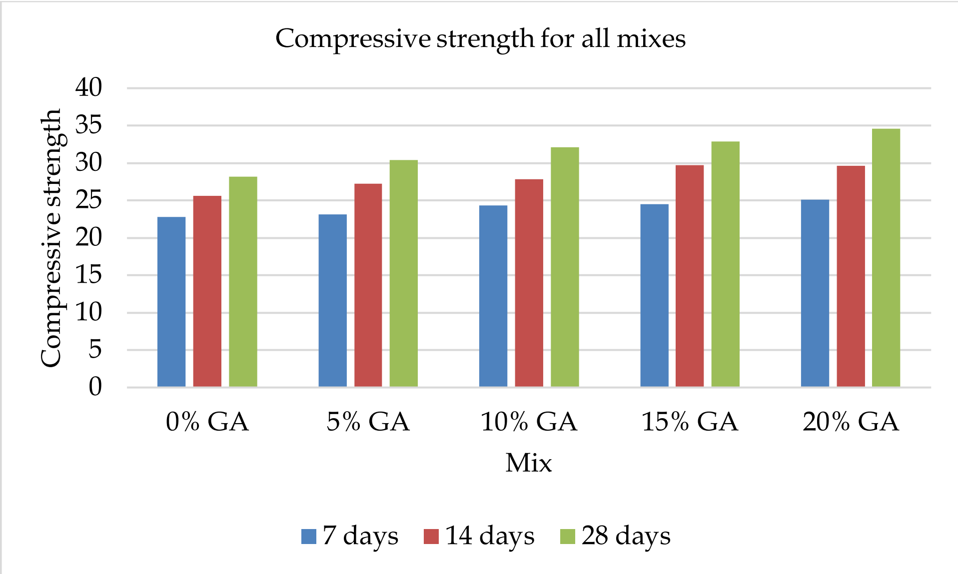

Fig.3 Comparison between the values of the compressive strength for control mix and mixes containing different glass aggregate replacements for different ages of curing at 0.45 w/c

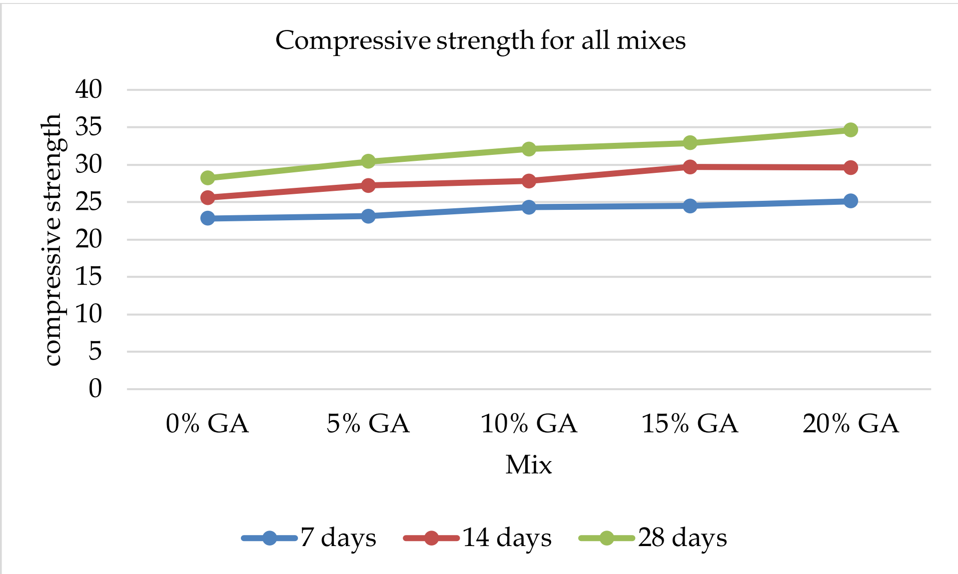

Fig.4 Compressive strength development for control mix and mixes containing different percentages of glass aggregate replacements at 0.45 w/c.

CONTRIBUTION TO KNOWLEDGE

This research has shown that fine aggregate can be conveniently replaced with waste glass at a reduced water-cement ratio and used as a concrete constituent to produce hardened concrete that compares favourably with normal concrete.

CONCLUSION

From the study, it can be concluded that the Compressive strength of the concrete with partial replacement of sand by finely crushed waste glass increased with an increase in the quantity of waste glass added. Concrete containing waste glass shows higher compressive strength at the later ages. Compressive strength at 28 days of concrete age with 20% crushed waste glass replacement of sand by waste glass gives higher compressive strength than the conventional concrete to about 25.2% at 0.5 w/c and for 0.45 w/c with 20% crushed waste glass replacement of sand by the waste glass the highest compressive strength was gotten and greater than the conventional concrete by about 22.7%. Thus the 20% replacement of finely ground waste glass with sand gives the maximum values of compressive strength at 28- days of age for both 0.45 and 0.5 w/c. There was a slight increase in the compressive strength of concrete at a reduced water-cement ratio; the highest increase of 7.64% was seen for the control mixes while the least of 2.17 was seen at 15% replacement of fine aggregate with waste glass between the 0.5 and 0.45 water cement ratios. On the overall, a 5.5% increase in compressive strength was observed when the water-cement ratio was reduced from 0.5 to 0.45 at 20% replacement of fine aggregate with waste glass. The slump of concrete containing waste glass as fine aggregate replacement decreased with an increase in the waste glass content. The 5%, 15% and 20% replacement of natural fine aggregate showed a progressive decreased value of slump compared to the control mix. There was a slight decrease in the slump values of concrete at a reduced water-cement ratio; the highest decrease of 29.2% was seen at 20% replacement while the least of 8.2% was seen in the control mix. The control mix had an 8.2% decrease in slump as compared with the 0.5 w/c indicating that at reduced water-cement ratio, glass concrete has lower slump and hence lower workability.

RECOMMENDATION

Waste glass can be conveniently used in concrete technology at a reduced water-cement ratio as the appropriate waste glass used as a sand replacement within the applied conditions showed good mechanical properties at 28 days.

CONFLICT OF INTEREST

I hereby state that no conflict of interest will arise in any form from the publishing of this study.

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