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# EXPERIMENTAL STUDY ON CONCRETE MADE WITH WASTE GLASS AGGREGATES

**Dr. Hala Metawei[1], Dr. Alaa F. Elkashif[2], Dr. Dalia Arafa[3], Dr. Nihal A. Taha[4]**

[1]Associate Professor, Housing and Building National Research Center, Cairo, Egypt
[2]Lecturer, Housing and Building National Research Center, Cairo, Egypt
[3]Lecturer, Housing and Building National Research Center, Cairo, Egypt
[4]Associate Professor, Housing and Building National Research Center, Cairo, Egypt

**ملخص البحث:**

يعتبر الزجاج من المواد التي يمكن استخدامها أكثر من مرة وإعادة تدويرها. زيادة عدد السكان وتطور مستوى المعيشة أدى الى زيادة مخلفات الزجاج. في هذا البحث تم استخدام الزجاج المعاد تدويره كبديل للرمل والسن. الزجاج المستخدم من بواقي شركات تصنيع الواح الزجاج وتم استخدام مقاسات مختلفة. تم استخدام المقاس الكبير بتدرج السن كبديل للسن بنسب 10%, 20%, و30%. المقاس الصغير تم استخدامه كبديل للرمل بنسب استبدال 10% و30% وتم عمل اختبار قابلية التشغيل للخرسانة الطازجة واختبارات مقاومة الضغط، مقاوم الانحناء ومقاومة التماسك (اختبار الاقتلاع) للخرسانة المتصلدة.

تم رصد نتائج جيدة للخرسانة المستخدم بها الزجاج كبديل للسن واختبارات مقاومة الضغط، مقاومة الانحناء ومقاومة التماسك (اختبار الاقتلاع) وكذلك تم رصد نتائج جيدة للخرسانة المستخدم بها الزجاج كبديل للرمل وان كانت اقل من استخدام الزجاج كبديل للسن.

## ABSTRACT

Glass is a material which could be used and recycled many times. Several tons of waste glass are generated annually worldwide due to the rapid growth of the population and improvement in the standard of living. In this study, waste glass was used as a partial replacment of both coarse and fine natural aggregates. The waste glass used came from firms that produce glass plates and was supplied with different sizes. The first particle size termed as coarse glass aggregates partially replaced natural coarse aggregate (dolomite) by weight at ratios 10%, 20% and 30%. The second particle size, termed as fine glass aggregate, partially replaced natural fine aggregates by weight at ratios 10% and 30%. Fresh concrete was tested for workability and hardened concrete was tested for compressive strength, flexure strength, and Bond strength.

A good performance was seen in concrete with coarse glass aggregates regarding to compressive strength, flexural strength and bond strength as well concrete with fine glass aggregates in spite it is less than concrete with coarse glass aggregate.

## Key Words

Sustainability, Recycled glass, concrete, bond, flexure strength.

## INTRODUCTION

Glass is a 100% recyclable material as its physical and chemical properties do not change. Like other waste materials (plastics, rubber, and ceramics) glass can be used in concrete as partial replacement of natural aggregate especially natural sand due to the similarities in physical properties and chemical compositions. Among the different waste material mentioned before, disposal of waste glass is still a major problem worldwide. Numerous efforts have been made within the concrete industry to use waste glass as a partial replacement of natural aggregates. The purpose of the study herein is to investigate availability of using domestic waste soda lime glass in concrete and its influence on its characteristics.

## RESEARCH SIGNIFICANCE

The study concentrated on studying the effect of using waste glass as a partial alternative of natural aggregates either fine or coarse in concrete mixture. Due to the lack in research related to bond and flexure strength characteristics, the study focused on forming several tests issuing both items.

## Historical Review

Review of literature on the hardened concrete Compressive strength containing glass aggregate

Even though results vary from study to study, it is found that increasing the incorporation of glass aggregates in concrete leads to a loss of compressive strength, but its value still increases over time, as in conventional concrete. Sepra et al. [1] replaced fine and coarse natural aggregates with fine and coarse glass aggregates up to 20% replacement ratio, they found that compressive strength was more effected by fine aggregates than by coarse aggregates this effect can be minimized by using super plasticizers to keep both the workability and the w/c constant in all mixture. Chen et al. [ 2] and Wang [3] replaced fine natural aggregates with fine glass aggregates from LCDs and although the compressive strength decreased, within each mixture it increased over time. Park et al. [4] also showed that increasing the replacement of natural aggregates by glass aggregates decreases the compressive strength, but there is no linear correlation between compressive strength and glass aggregate content. However, Limba- chiya [5] demonstrated that for replacement ratios up to 20%, the compressive strength does not change significantly, but it does for higher ratios. For bigger aggregates Topçu and Canbaz [6] reported a decrease of the compressive strength as the replacement ratio increased and noted that there was proportionality between the loss of compressive strength and the glass aggregate incorporation ratio. Kaveh and Prasada [10] focused in their study on quantifying the impact of using glass powder in concrete, both as an aggregate replacement material and cement replacement material, on the fresh and hardened concrete properties. They concluded that, the 28-day compressive strength value of the concrete specimens with glass aggregate containing 20% glass powder enhanced the compressive strength by 26% more than that of the concrete mixtures with mineral aggregates.
Rajagopalan et al. [7] using (50%) waste glass as fine aggregate concrete showed a percentage reduction of 5%, compared to control concrete and using coarse aggregate concrete fully replaced with waste glass as coarse aggregate concrete showed a percentage reduction of 20%, compared to control concrete in compressive strength.
Wang F. et al. [8] using replacement levels of 25%,50%, 75%, and 100% for Glass Coarse Aggregate and Glass Fine Aggregate. At the same GA replacement level, the cubic compressive strength of GFA concrete are larger than those of GCA concrete.

Review of literature on the hardened concrete Flexure strength containing glass aggregate

Another important characteristic of concrete is its flexural strength. Topçu and Canbaz [6] had no conclusive results, because there is an apparent decrease in flexural strength as the incorporation of glass aggregates, increases but the comparison of different concrete families does not show a direct correlation between coarse glass aggregates and flexural strength. In concrete with fine glass aggregates, Park et al. [4] showed a decrease in 28-day flexural strength with higher fine glass aggregates content, but no linear correlation, because the flexural strength drop between 0 and 30% incorporation is much less pronounced than it is between 30 and 50 % and between 50 and 70 %. Limba-chiya [5] showed there was a decrease in flexural strength, but only for ratios of 20% or more; for lower ratios, the flexural strength was the same as that of the reinforced concrete. Wang [3] found a reduction of 28-day flexural strength for greater fine glass aggregates incorporation ratios.

Review of literature on the hardened concrete bond strength containing glass aggregate

Concrete that is brittle, nonetheless strong in compression and relatively durable with reinforcing steel that is strong and ductile in tension. Keeping composite action needs a transfer of load between concrete and steel. Bond is affected also by the formulation of concrete.

Wang et al [8], reports on an investigation of glass aggregate concrete bond behavior. Nine pullout tests were carried out on 16 mm diameter deformed steel bars concentrically embedded in glass aggregate concrete using equivalent mix proportions with glass coarse aggregate and glass fine aggregate at replacement levels of 25%,50%, 75%, and 100%. Analysis of the measured bond-slip relationships indicates mechanisms of bond resistance in the glass aggregate similar to natural aggregate concrete, was used to acquire the most accurate and conservative predictions of measured bond strengths. The failure mode of natural aggregate and glass coarse aggregate concretes' bonds with rebar is a split failure, whereas the failure mode of glass fine aggregate concrete's bond with rebar changes from a split to a pullout failure with increasing glass fine aggregate replacement levels. The normalized ultimate bond strengths of the glass fine aggregate concretes are higher than those of the glass coarse aggregate concretes and the normalized ultimate bond strengths of glass coarse aggregate concrete and the glass aggregate replacement level relationship are almost linear. The test results show that reasonable glass fine aggregate replacement levels can improve the bond behavior of concrete with steel rebar.

Rajagopalan et al. [7] conduct pull-out test on both control and Waste Glass Aggregate cube specimens (150 mm x 150 mm with 20 mm diameter steel rods). Failure of pull out specimens occurred due to failure of the concrete enclosing the rebar. Pullout test on specimens showed that the bond strength of waste glass fine aggregate concrete increased by 5%, compared to control concrete. Pull-out test on specimens showed that the bond strength of waste glass coarse aggregate concrete decreased by 25%, compared to control concrete. Comparison of the results with that of control specimens showed that waste glass could be effectively used as aggregates in reinforced concrete construction. Unfortunately, the studies of bond behavior between concrete with glass aggregates and steel is few relative to studies of bond between concrete with normal aggregate and steel.

Wang F. et al. [18] The bond-slip curves of glass aggregate concrete and steel bars have four typical stages: initial slip, slip-splitting, descending, and residual stages. The normalized ultimate bond strengths of the glass fine aggregate concretes are higher than those of the glass coarse aggregate concretes; the relationship between the normalized ultimate bond strength of glass coarse aggregate concrete and the glass aggregate replacement level is almost linear. The ultimate bond stress of glass coarse aggregate concrete is smaller than that of natural aggregate concrete, but the bond stress of glass fine aggregate concrete is greater than that of natural aggregate concrete.

## EXPERIMENTAL PROGRAM

Natural siliceous sand and crushed stone had a nominal maximum size of 10 mm. Ordinary Portland Cement and tap drinking water were used in this work. The source of waste glass was the disposal of a glass production factory. This glass was collected, screened, washed, and crushed to standard size ranges used in this research are shown in Table 1. In accordance with Egyptian Code of Practice for Reinforced Concrete Construction [9] concrete was produced with a target compressive strength, measured in cubes, of (30 MPa), and workability within the slump range (Abrams cone test) of (30-120 mm). The Mixture design quantities for one cubic meter are shown in Table 2.

**Table 1: Grading of coarse and fine glass aggregate**

| Sieve Size (mm) | % of passed coarse glass aggregate | | % of passed fine glass aggregate |
|---|---|---|---|
| | size 2 | Size 1 | |
| 63 | 100 | 100 | 100 |
| 40 | 100 | 100 | 100 |
| 31.5 | 100 | 100 | 100 |
| 22.4 | 100 | 100 | 100 |
| 16 | 99.4 | 99.76 | 100 |
| 11.2 | 63.8 | 77.8 | 100 |
| 5.6 | 27.56 | 15.26 | 100 |
| 4 | 12.72 | 2.38 | 98.7 |
| 2 | 7.1 | 0.42 | 88.7 |
| 1 | 3.66 | 0.42 | 51.4 |
| 0.25 | 2 | 0.42 | 13.4 |
| 0.125 | 2 | 0.42 | 3.9 |
| 0.063 | 2 | 0.42 | 3.3 |

**Table 2: Mixture design**

| Mixture ID | Cement (kg) | Coarse aggregate (dolomite) (kg) | Coarse glass aggregate (kg) | Fine aggregate (Sand) (kg) | Fine glass aggregate (kg) | Water (liter) |
|---|---|---|---|---|---|---|
| **G0** | 350 | 1068 | 0 | 712 | 0 | 200 |
| **CGA10** | 350 | 956 | 112 | 712 | 0 | 200 |
| **CGA 20** | 350 | 850 | 218 | 712 | 0 | 200 |
| **CGA 30** | 350 | 743 | 324 | 712 | 0 | 200 |
| **FGA 10** | 350 | 1068 | 0 | 641 | 71 | 200 |
| **FGA 30** | 350 | 1068 | 0 | 498 | 214 | 200 |

The glass aggregates were incorporated in concrete as replacement by weight of natural aggregate, according to their size (that is, keeping the grading distribution constant in all mixtures). A total of six concrete mixtures were prepared. The replacement ratios were determined as a function of the overall weight of fine and coarse aggregates. Concrete mixtures containing 60 % of glass aggregate size 2 and 40 % of glass aggregate size 1 remixed to use as coarse aggregate. The coarse glass aggregate replacement in percentages 10, 20, and 30% are nominated as CGA10, CGA 20 and CGA 30 mixtures. The fine glass aggregates in percentages 10 and 30% replacement are nominated as FGA 10 and FGA 30. The glass beads sizes are shown in Fig. 1. Finally, the water-cement ratio (w/c) was kept constant in all mixtures as shown in Table 2.

**(a) Coarse glass** **(b) Fine glass**

**Fig. 1: Glass Aggregates Sample**

## PREPARATION OF TEST SPECIMENS AND TEST SETUP

The concrete mixtures were prepared as follows: the mixer was prepared and pre-wetted and the coarse aggregates, fine aggregates, half the water, the cement, and the rest of the water with glass were added in that order. Three minutes were needed for the mixture to become homogeneous, and the whole mixing process took approximately 5 minutes. All the molds were lubricated and then the concrete was cast and vibrated. After 24 hours, the specimens were demolded and left to cure. Fig. 2 shows Specimens in mold.

**Fig. 2: Specimens in mold**

### Slump test

Slump test was performed to evaluate the consistency and workability of fresh concrete mixture. The test was carried out according to the Egyptian Specifications [10] as shown in Fig. 3.

**Fig. 3: Slump test**

Table 3 shows the slump values of the concrete mixtures containing glass as natural aggregate replacement. Results shows that for original mixture the slump was 55 mm while for mixtures with coarse glass aggregates the slump decreased, while for mixture with 30 % replacement with coarse aggregate the slump value increases. however, for mixtures with fine glass aggregates the slump increased, which indicates that the use of fine glass particles increase the workability of the concrete mixtures compared to concrete mixtures containing natural mineral aggregate. Kaveh and Prasada [11] related the positive affect on workability in case of coarse glass particles to the thin and elongated geometrical shape of the particles when used as coarse aggregate replacement. However, when glass powder is used as fine aggregate replacement the powder content (cement and glass) increase and due to high surface area, high water demand is needed.

### Compressive strength

Tests to determine the compressive strength of the concrete were carried out after twenty-eight days. Three cube samples from each concrete mixtures were casted into prepared concrete molds with size 150*150*150 mm. There were thus 18 cube to be tested in total. Concrete was allowed to air-cure for a period of 24 hours, before removed from molds and transferred to a water bath. Once being removed from the curing bath after 28 days, cubes were allowed to surface dry before their weight was measured and placed into the testing machine. Average Compressive strength values for each mixture are presented in Table (4).

**Table 3: Slump values of Concrete Mixtures**

| Mixture ID | Slump Value (mm) | Consistency of Concrete |
|---|---|---|
| **G0** | 55 | Plastic |
| **CGA10** | 50 | Plastic |
| **CGA 20** | 52 | Plastic |
| **CGA 30** | 70 | Plastic |
| **FGA 10** | 65 | Plastic |
| **FGA 30** | 60 | Plastic |

**Table 4: 28-days compressive strength of concrete cubes**

| Mixture ID | $f_{cu}$ (N/mm$^2$) at 28 day |
|---|---|
| **G0** | 25.40 |
| **CGA10** | 31.10 |
| **CGA 20** | 27.10 |
| **CGA 30** | 29.80 |
| **FGA 10** | 31.00 |
| **FGA 30** | 27.00 |

The comparison between compressive strength results following 28 days of curing can be seen in Fig. (4).

According to Table 4, It closely mirror that, all mixtures compressive strength values were higher compared to the control mixture G0. The mixtures with the best results relative to the G0 were CGA10 and FGA10 with an increase in strength equal to 22.44%. Less values were by replacing natural coarse aggregates by 20% of coarse glass. In mixture CGA30 and FGA30 replacing natural aggregates by 30% an increase in strength equal to 6.69% and 6.30% respectively, compared to control mixture G0.

Overall, the increase in strength may be attributed to the reduction in the proportion of glass aggregates below 30% in the concrete mixture, as the reduced level of glass aggregate content may be somewhat beneficial considering that the smooth surfaces of the glass aggregate particles and poor bonding to the paste at early ages decrease the mechanical properties of concrete [11]. In addition, in the long term, the pozzolanic reaction between glass particles (glass sand) and cement paste could modify and enhance the microstructure at interface transition zone, leading to an obvious increase in strength regardless of concrete mixture [12].

The increase in the strength above may be also attributed to the angular nature of glass aggregate, which has a greater surface area than the naturally rounded sand particles. This allows for greater bonding with the cement paste, resulting in a stronger concrete matrix [13].

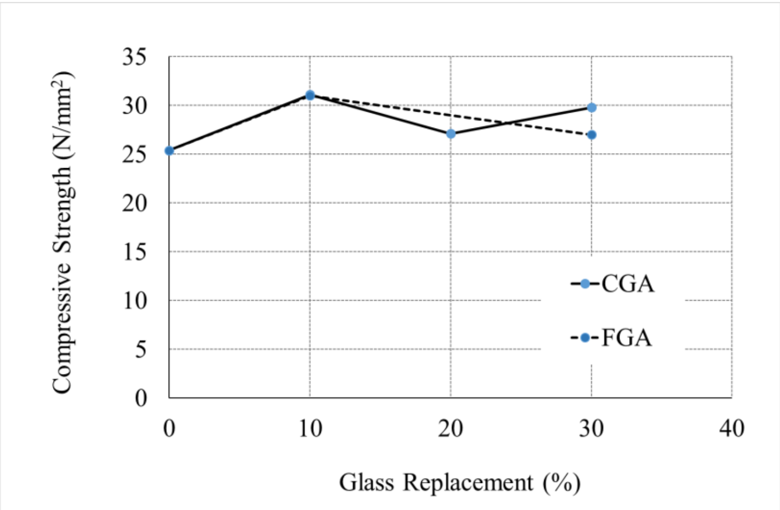


**Figure (4): Comparison between Compressive Strength Values for different Concrete Mixtures**

**Flexural beam test**

The flexural beam test is conducted by testing three plain concrete beams for each mix with dimension 100*100 *500 mm to determine Flexural strength (modulus of rupture). The test setup for bending test shown in Fig. 5. The flexural strength results are shown in Table 5. The result of Flexural strength calculated by two methods, firstly, using equation (1) according to bending theory. The second one by using ACI 318 [14] most commonly used equation relating the compressive strength of normal-weight concrete and its modulus of rupture equation referred as equation (2).

The flexural strength is calculated as the ratio of the calculated maximum bending moment and section modulus of the beam specimen. The flexural strength was calculated by the relation:

$$f_b = \frac{M_{max}Y}{I} \quad (1)$$

Where:

$f_b$ : flexural strength or modulus of rupture

$M_{max}$ : Maximum bending moment measured from flexure test

I: Moment of inertia

Distance between neutral axis and max section fiber Y $Y = \frac{h}{2}$

$$I = \frac{bh^3}{12}$$

$f_r = 0.62\sqrt{f_{cu}}$ N/mm$^2$. (2)

Where:

$f_r$ = modulus of rupture, $f_{cu}$= compressive strength

**Fig. 5: Test setup for flexural strength**

The modulus of rupture calculated using Equation 1 is not a true representative of the tensile strength of concrete since it assumes the applicability of Hooke's law of stress-strain proportionality throughout the depth of the beam. Since concrete deformations do not follow Hooke's law, the formula results in fictitious tensile stress values that are lower than the actual stresses in the beam. In fact, concrete researchers [10-14] have indicated that the true tensile strength is about 65 to 70 percent of the modulus of rupture. Nevertheless, the compressive strength and the modulus of rupture are closely related. As the compressive strength increases, the modulus of rupture also increases in general in case of natural aggregates, while in our case, the flexural strength decrease by presence of glass aggregates. But for 30 % replacement of coarse aggregate the flexure strength is the same as the reference mixture. Adversely in fine glass aggregate the flexural strength decrease with increasing the percentage of fine glass.

In general, the flexural strength of coarse aggregate replacement is higher than fine aggregate replacement.

**Table 5: Test Results for compressive strength, modulus of rupture (flexural strength)**

| Mixture ID | modulus of rupture (flexural strength) ($N/mm^2$) | |
|---|---|---|
| | $f_b$ | ACI $f_r = 0.62\sqrt{f_{cu}}$ |
| **G0** | 5.10 | 3.12 |
| **CGA10** | 4.62 | 3.46 |
| **CGA 20** | 4.20 | 3.23 |
| **CGA 30** | 5.10 | 3.38 |
| **FGA 10** | 3.60 | 3.45 |
| **FGA 30** | 3.12 | 3.22 |

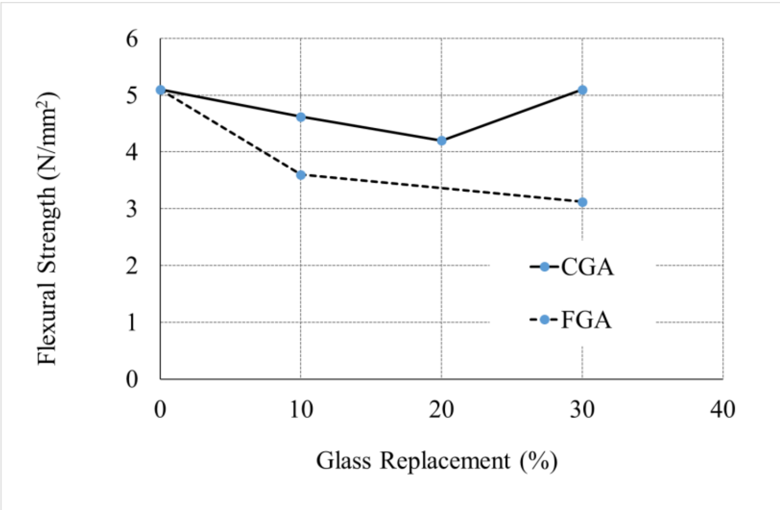


**Figure (6): Comparison between Flexural Strength Values for different Concrete Mixtures**

**Pullout test**

Eighteen pullout test specimens were casted to determine the bond between concrete mixes and steel bar. All the steel bars were 360 grade deformed steel bars with nominal diameters of 12 mm using concrete cylinder of diameter 150 mm and height 300 mm. Fig.7 shows test setup for pullout test. Table 6 represent test results for pullout test. The bond strength was computed using equation (3) as follow:

$S = \frac{P}{\pi d L}$ (3)

where
S: bond strength
P: ultimate load
L: embedded length
d: bar diameter

**Fig. 7: setup for pullout test**

The pullout test specimens failed by the following three modes of failures, pullout failure, splitting failure of the tested specimen and steel rupture failure. In case of coarse aggregate, the used crushed glass aggregate has higher values of pullout bond strength compared to the control by 9.59% and 4.11% for 10 % and 20 % replacement, respectively, however, slightly decreased for 30 % replacement. On the other hand, for fine glass replacement, there is a decrease in both ratios of replacement 10% and 30 % by 16.44 % and 26.03 %, respectively. Furthermore, it is obvious that concrete mixes with fine glass aggregates failed in a brittle manner, and the specimens failed abruptly forming longitudinal splitting cracks causing bond failure in highly abrupt and brittle manner. Moreover, the bond stress reduces drastically. This can be explained on the basis of fracture mechanism. According to energy criterion of fracture mechanism, strain energy keeps on accumulating in the material as micro cracking propagates at about 70–80% of the ultimate load. As soon as a primary crack forms along the boundary between steel and concrete, it immediately leads to crack propagation utilizing accumulating strain energy.

We can conclude that the bond strength of coarse aggregate replacement is higher than fine aggregate replacement as shown in Fig.(8).

**Table 6: Test results for pullout test**

| Mixture ID | Pull out force (kN) | Ultimate tensile pull-out bond strength ($N/mm^2$) | Ultimate slip (mm) | Presence of cracks | Failure Mode |
|---|---|---|---|---|---|
| **G0** | 73 | 6.45 | ---- | No cracks | Steel rupture |
| **CGA10** | 80 | 7.07 | 5 | No cracks | pullout |
| **CGA 20** | 76 | 6.72 | 10 | No cracks | pullout |
| **CGA 30** | 72 | 6.36 | 34 | No cracks | pullout |
| **FGA 10** | 61 | 5.39 | 45 | No cracks | pullout |
| **FGA 30** | 54 | 4.77 | ---- | cracked | Splitting |

## CONCLUSION

Strength characteristics of concrete produced with partial replacement of natural coarse and fine aggregate with waste glass was carried out and following conclusions were arrived.

1. Slump test for waste glass aggregate concrete were conducted and plastic Consistency of concrete has been achieved.
2. All mixtures compressive strength values were higher compared to the control mixture. The mixtures with the best results relative to the control one were coarse glass aggregate 10% replacement and fine glass aggregate 10 % with an increase in strength equal to 22 % compared to control mixture. Less values were by replacing natural coarse aggregates by 20% of coarse glass and replacing natural fine aggregates by 30% of fine glass with an increase in strength equal to 6.70% and 6.30% respectively, compared to control mixture.

3. The flexural strength decrease by presence of glass aggregates. But for 30 % replacement of coarse aggregate the flexure strength is the same as the reference mixture. Adversely in fine glass aggregate the flexural strength decrease with increasing the percentage of fine glass.

4. The bond strength of coarse aggregate replacement is higher than fine aggregate replacement. In case of coarse aggregate, the used crushed glass aggregate has higher values of pullout bond strength compared to the control by 9.59% and 4.11% for 10 % and 20 % replacement, respectively, however, slightly decreased for 30 % replacement. On the other hand, for fine glass replacement, there is a decrease in both ratios of replacement 10% and 30 % by 16.44 % and 26.03 %, respectively.

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