Influence of Incorporating Waste Glass Powder and Fine Waste Plastic Aggregate on Fresh and Hardened Properties of Structural Concrete

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Abstract. This research aims to create green concrete with acceptable characteristics by recycling glass and plastic waste together. Cement was partially replaced with a 15% waste glass powder by weight mixture and fine aggregates with a 5% waste plastic crushed mixture. According to the findings, adding glass alone to concrete enhanced its qualities, such as compressive strength, splitting tensile strength, flexural strength, energy capacity, and bond strength, compared to a reference sample. The splitting tensile strength increases with replaced cement by 15% glass by 5.4%. When replacing fine aggregate with 5% fine plastic, splitting strength decreases by 5.4%. Flexural strength increased by 1.6% when adding 15% glass to the reference mixture. On the other hand, replacing sand with plastic for concrete with 15% glass powder led to some properties of concrete being affected downwards.

Keywords: Glass powder; Waste plastic; bond; Compressive strength; Partial replacement.

1. INTRODUCTION

The main ingredient in concrete, cement, releases a sizable amount of greenhouse gases during production. According to estimates, 870 kilograms of CO_2 are released while manufacturing one ton of Portland cement. [1]. So reducing the amount of cement will be helpful environmentally by replacing it partially with powder from waste like waste glass powder. Using glass powder in concrete improves the structural behavior of reinforced concrete beams in both flexural and shear [2]. Another study worked to investigate fresh and hardened characteristics of concrete by using glass powder resulting from melted or broken windows as a partial cement replacement. Five mixes were created in this study with different percentages of waste glass powder used as cement substitute at 0, 10, 15, 20, and 25% by weight. They found that compressive strength with 10,15 and 20% of waste glass powder increased by 27.62, 41.46, and 20.18% at 28 days. While at 56 days, compressive strength increased by 22.11, 41.75, and 21.36% at 56 days, and 27.05, 30.81, and 17.2% at 90 days for 10, 15, and 20% of waste glass powder, respectively, compared to reference specimens. Otherwise, 25% of waste glass powder caused a decrease in compressive strength by 14.34, 20.5, and 19.41 at 28, 56, and 90 days, respectively, compared to the reference mix. In addition, mechanical properties were improved by adding glass power [3], [4].

Waste plastic has been utilized in concrete as fine or coarse aggregate, partially replacing natural material. Hosseini et al. [4]. Waste PET (polyethylene terephthalate) was used in another investigation as fine and coarse aggregate in the mixed design of polymer concrete. The findings revealed that. Regarding increasing fracture toughness and energy, coarse PET outperformed fine PET. This was explained by coarse PET's capacity to fill fissures[5]. Saxena et al. used Waste PET type as fine and coarse particles in concrete from 0 to 20% [6]. They discovered no enhancement in the mechanical characteristics and increased a note of improvement in the abrasion resistance but not in the water absorption [6]. In general, researchers showed that utilizing waste plastic, regardless of its type or size, improved the impact resistance of concrete and made its failure more ductile [7].

Different sizes of waste plastic have been used in concrete, and some researchers have employed it as an inexpensive fiber to strengthen weak concrete. concrete's composition. They discovered that adding waste plastic as fibers decreased mixes' workability and compressive strength [8-11]. In a different investigation, plastic aggregate made from discarded garbage bags was also employed at levels ranging from 0 to 20% with 5% increments. Moreover, The findings showed that while impact strength, abrasion resistance, and energy absorption greatly improved, concrete's compressive strengths declined [12]. Most studies indicated that concrete's impact resistance was increased by utilizing discarded plastic as fibers or particles as fine or coarse aggregate [13]. This effort aimed to utilize both wastes to benefit from waste's impact on concrete and to close the knowledge gap on the effects of mixed waste glass powder with waste plastic as fine aggregate. The best results were obtained with 15% of waste glass powder, according to Yassin et al. [3, 14] and Mahmoud et al. [4], who substituted cement with various percentages of glass powder 15% is the best content to use as a partial replacement for cement.

Using more than 5% plastic as aggregate led to a decline in concrete fresh and hardened properties [15],[16]. Therefore, 15% glass powder with 5% plastic as fine aggregate has been utilized.

Throwing large quantities of broken glass waste and plastic waste as a result of various life uses calls for finding a practical and clean way to get rid of these solid and non-biodegradable waste. One of these solutions is to exploit them by producing green concrete. Mohammed and Hama [2] combined 15% of glass powder with two percentages of the fine plastic aggregate 10% and 20%, but through our review of previous studies, it was found that the percentage of plastic aggregate was less than the best to preserve as much as possible the properties of concrete, so 15 percent of glass powder with 5% plastic aggregate.

2. EXPERIMENTAL PROGRAM

2.1 Materials and Mixing Proportions

All of the concrete mixtures in this investigation were made with Portland cement, which had a specific gravity of 3.15. This type I cement satisfied Iraqi specification No. 5 [17]. Broken windows were used to prepare the glass powder for this investigation. This trash was taken from broken windows in the old building. The gathered glass was then cleaned to remove impurities and dust, broken with a crusher, and ground to powder pass through a sieve of 0.75μm. Natural sand was used as a fine aggregate in this research, with a maximum size of 4.75 mm and a specific gravity of 2.62. Additionally, crushed gravel with a maximum particle size of 10 mm and a specific gravity of 2.68 was used as a coarse aggregate. Tables 1 and 2 show the sieve analysis of aggregates. The polyethylene plastic utilized in this investigation was leftover from the deforming and dissolving process used to make the valve for cooking gas bottles. It was white with a specific gravity of 1.56. The plastic sieve analysis is listed in Table (3). The used natural aggregate satisfied Iraqi specification No. 45 [18]. Tap water was used for mixing and curing specimens and for all concrete mixes. Superplasticizers, types F and G, according to ASTM 494 [19] were used in this research. The materials are illustrated in Figure 1.

Table 1: Sieve Analysis of Fine Aggregate.

Sive size (mm)	10	4.75	2.36	1.18	0.6	0.3	0.15
Cumulative passing, %	100	97.1	82.2	66.4	49.4	16.2	2.1
IQS limits, zone 2	100	90-100	75-100	55-90	35-59	8-30	0-10

Table 2: Sieve Analysis of Coarse Aggregate.

Sive size (mm)	14	10	5	2.36
Cumulative passing %	100	94.5	0.5	0.2
IQS limits	100	85-100	0-25	0-5

Table 3: Sieve Analysis of Waste Plastic Fine Aggregate.

Sive size (mm)	10	4.75	2.36	1.18	0.6	0.3	0.15
Cumulative passing %	100	99.2	16.6	3.8	1.6	0.6	0.3

Figure 1: Materials used in this work.

A mixing ratio of (1:1.75:2.5) for cement, fine aggregate, and coarse aggregate was used in the casting of samples with 0.34 water-to-cement ratio (w/c) and 1.25% superplasticizer. The concrete was cast into the molds and preserved in the laboratory for 24 hours. The specimens were placed in a water curing pool for 28 days then they were tested.

Table 4: Mixes proportions (kg/m^3).

Materials	Mixes			
	0P0G	**5P0G**	**0P15G**	**5P15G**
Cement	400	400	340	340
Sand	700	660	700	660
Gravel	1000	1000	1000	1000
water/cement	0.34	0.34	0.34	0.34
Plastic aggregate	-	40	-	40
Glass powder	-	-	60	60
Superplasticizer	1.25%	1.25%	1.25%	1.25%

2.2 Experimental Tests

The slump test was conducted according to ASTM C143/C143M [20]. Cylindrical specimens with dimensions of (150×300 mm) were tested to find compressive strength (f 'c) (i.e., the strength of concrete mixtures after 28 curing age), according to ASTM C39/C39M [21]. A splitting tensile strength test was carried out in the same compressive strength test machine on cylindrical samples (100×200) mm after 28 days of curing. This test was performed following ASTM C496/C496M [22]. A flexural strength test was carried out with a hydraulic machine on prismatic samples with a length of 500 mm with section (100 × 100 mm) according to ASTM C78/ C78M [23]. The impact test was carried out following ACI 544.2R [24] on a concrete disk with a diameter of 150 mm and a height of 63.5 mm. A hammer weighing (4.536 kg) was dropping repeatedly from a height (0.4572 m) on an iron ball of 1182 g in the sample center. The test was carried out until each sample of concrete failed. The number of blows was recorded, and the amount of the energy absorbed was calculated using Equation (1):

$$EI = Nmgh \quad (1)$$

According to RILEM-TC RC 6 [25], a cubic sampler with dimensions of (100×100×100 mm) and a steel bar of φ10 mm were used. The rebar was 550 mm in length, 50 mm outside the cube, and 100 mm was cast into the concrete cube. The tests made in this work are illustrated in Figure 2.

Figure 2: Tests conducted in this work.

3. RESULTS AND DISCUSSION

3.1 Workability of Fresh Mix

The slump test revealed that adding plastic aggregate (P) and glass powder (G) to the concrete mixture reduced the slump value by (22.2%, 27.8%, and 44.4%) for (5P, 15G, and 5P&15G), respectively, compared with the reference mixture (0P0G), See Figure 3. The reduction in a slump with replacing sand with plastic aggregate was due to the sharp and irregular edges of plastic waste particles, which increased the friction between particles and caused a reduction in workability. A reduction in slump was also found by other researchers who also used different types of waste plastic [26]. Jain et al. found that the slump decreased from 81 mm for the control mix to 12 mm for the mix with 20% fine plastic aggregate [12].

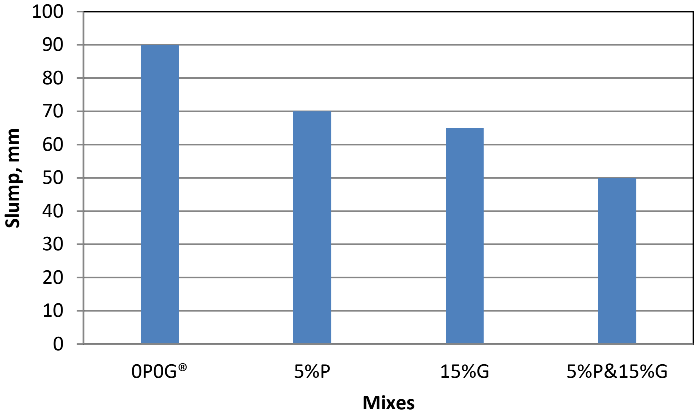

Figure 3: Slump test results for all mixes.

3.2 Mechanical Properties

As shown in Figure 4, the compressive strength increased by 15% G. For specimens 5P and 5P&15G, the compressive strength decreased. The reason behind the increasing strength in the case of replacing part of cement with glass powder can be explained as follows: Pozzolanic activity is the ability of pozzolan to react with Ca+ 2 or calcium hydroxide $Ca(OH)_2$ in the existence of water. The pozzolanic response is dependent on the pozzolan properties, such as chemical composition and surface area. The glass contains a large quantity of silicon and calcium. Therefore, as soon as it is finely milled to particle sizes smaller than 75 microns, it can be used as a cement replacement in concrete. Cement paste shows pozzolanic properties when substituted with glass powder at 10% and 20% replacement ratios. The formation of C–S–H with consumption of $Ca(OH)_2$ is higher for the (38 microns) glass replaced compared with (75–150 and 38–75) microns because of the activity of fine particle size [27,28].

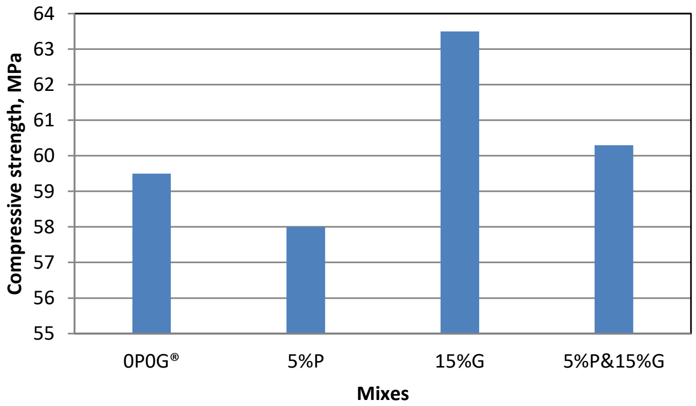

Figure 4: Compressive strength test results for all mixes.

As shown in Figure 5, the splitting tensile strength increases with replaced cement by 15% G by 5.4%. When replacing fine aggregate with 5% P, splitting strength decreases by 5.4%. But when 5P&15G, the splitting strength decreased by 3.5%.

 https://doi.org/10.1051/e3sconf/202342702003

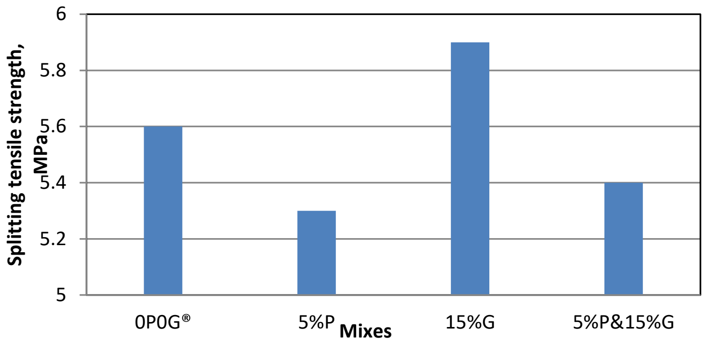

Figure 5: Splitting strength test results for all mixes.

The results of the flexural strength test are shown in Figure 6. Flexural strength increased by 1.6% when adding 15% G to the reference mixture and decreased by (3.2% and 9.6%) when adding (5P,5P&15G) respectively with 15% glass to the mixture. The increase in splitting and flexural strengths due to incorporating glass powder is mainly attributed to the same factors that cause an increase in compressive strength [3,4]. These results are close to those of Yassin et al. [3] and Mahmoud et al. [4]. Also, incorporating plastic aggregate into the concrete matrix decreased splitting and flexural strength due to weak bonds between the aggregates and paste matrix, and specimens failed by debonding from the cement paste [16].

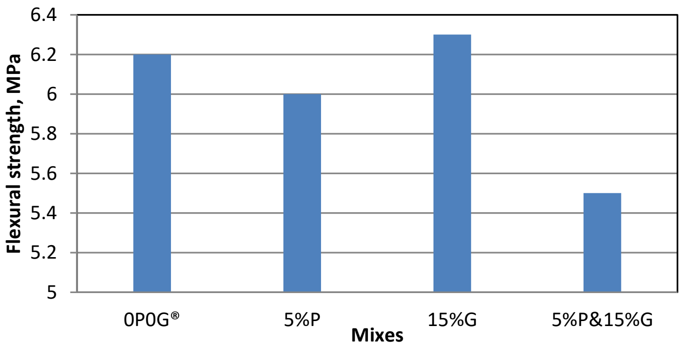

Figure 6: Flexural strength test results for all mixes.

3.3 Impact Energy Capacity

The results showed, as in Figure 7, a significant rise in the ability of energy absorption of the concrete samples by replacing cement with G, and a higher rise was observed by replacing sand with plastic aggregate. The increase was (131.9, 92.8, and 267.8%) for (5P, 15G, and 5P&15G), respectively, compared to 0G0P. Concrete energy absorption increased as plastic aggregate content increased due to plastic's high elastic properties and flexibility compared to natural aggregate, which enhanced the ductility of concrete and increased the energy absorption ability of specimens. Similar results were obtained by other researchers who used different types of plastic, but all results referred to an improvement in impact resistance by adding plastic to concrete[29-31].

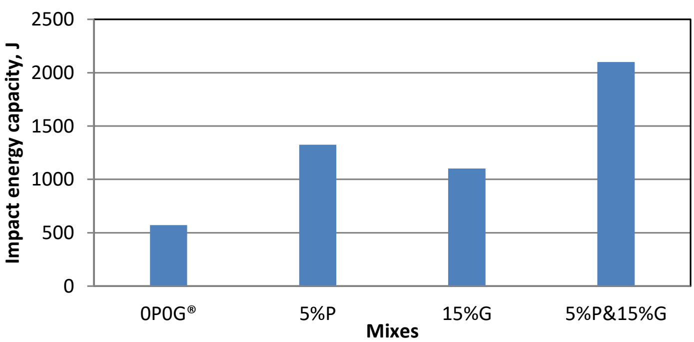

Figure 7: Impact energy for all mixes.

3.4 Bond Strength between Concrete and Reinforcing Bar

Figure 8 indicates that the bond strength between concrete and steel reinforcement increases with the addition of glass and decreases with the addition of plastic. This change was (-2.9%, + 0.6%, and – 1.2%) for (5P, 15G, and 5P&15G), respectively. The reason for reducing the bond strength by incorporating plastic is due to a lack of chemical reaction between plastic aggregate and the cement paste. The other reason is the smooth surface of the plastic used in this study, which results in a weak bond between the cement matrix and the steel bar [36]. Because glass partials, especially the fine ones smaller than 75 microns, serve as pozzolanic material, this behavior can be explained by reacting with calcium hydroxide to create cement gel (C-S-H), which fills in gaps, capillary holes, and transition zones and strengthens the bond between concrete and steel reinforcement bars. These findings concur with those of Ubeid et al. [32]. All specimens failed by splitting, as shown in Figure 9.

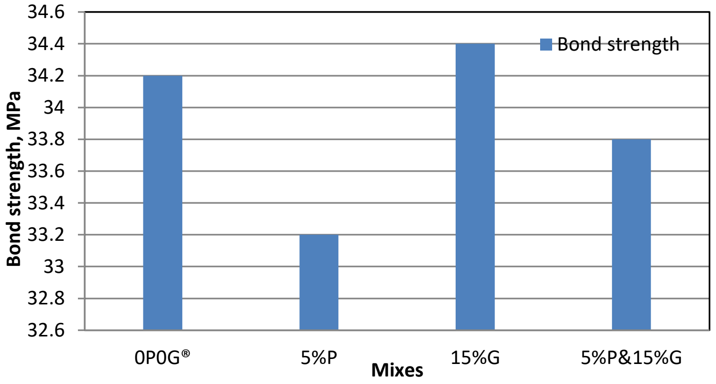

Figure 8: Ultimate bond strength for different all mixes.

Figure 9: Specimens after failure in bond test.

4. CONCLUSIONS

- Due to the irregular shapes of plastic particles, the slump was decreased, which led to a decline in the workability of the mix. Using a combination of glass powder and fine plastic aggregate led to an extra decrease in slump value.
- The 15% glass powder improved the properties of concrete, such as compressive strength, splitting tensile strength, and flexural strength. Improvement in the concrete strengths was noticed compared to that of control concrete mixes. This is due to the high SiO_2 content of glass powder, which made it act like pozzolanic material reacted with CaOH from cement hydration.
- The energy capacity was improved by replacing sand with 5% plastic aggregate and cement with 15%glass powder.

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