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Research paper

Experimental investigation of using recycled glass waste as fine aggregate replacement in concrete

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Abstract: Environmental problems are considered a serious situation in modern construction. Reusing and recycling glass wastes is the only method to decrease waste produced. There is growing environmental compression to decrease glass waste and to reprocess as much as possible. In this investigational work, the effect of partially substituting crushed waste glass in concrete is considered. The study investigates crushed waste glass used as a partial replacement of fine aggregate for new concrete. recycled glass waste was partially replaced as 5%, 10%, 15%, 20%, 25%, 30, 35, 40%, 45%, 45% and 50% and tested at 7, 14 and 28 days of curing at 20° for mechanical properties and compared with those of controlled mix. The compressive strength, splitting tensile strength and flexural forces and static elasticity modulus of specimens with 20% waste glass content was 30%, 19.41%, 9.13% and 10.12%, respectively, which is higher than the controlled mix at 28 days. The outcomes displayed that the maximum rise in strength of concrete occurred when 20% replacement with glass crush. It is found that crushed waste glass can be used as fine aggregate replacement material in concrete production.

Keywords: crushed waste glass, partial replacement of fine aggregate, normal concrete, disposal problem, mechanical properties

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1. Introduction

The concentration of the construction society in using recycled resources like recycled glass waste in concrete is growing. Since the request in concrete manufacturing is increasing day by day, efforts are made in using recycled glass waste as fine aggregate in replacement of river sand. The recycled resources and glass powder were used as fine aggregate in concrete production [1–4]. to understand the effect of glass powder on the inflexibility and workability of the concrete. the crushed waste glass was added to the concrete mixture as fine aggregates. The outcomes presented that it lesser the cost of the concrete manufacture but it had no distinguished consequence on the workability nor the inflexibility [5]. employing the waste glass to replace sand in diverse percentage levels (10% to 30%), and 10 mm granite in diverse percentages (5% to 15%). This leads to a good relationship between the crushed waste glass and air content. moreover, there is an opposite relationship between the recycled glass powder and the drying reduction [6]. In contrast, glass powder waste thought out to be a supplementing cementing material and there is a relation between the pozzolanic and the mote size. Also, the addition of lithium can hold a pozzolanic increase in size [7].

Palmquist [8] utilized the crushed glass, like other types of recycled material, as an aggregate in mortar. This recycled material has been studied in mortar workpieces and exams on mortar with crushed waste glass aggregate. Eventually, the compressive strength of the mortar with waste glass is less than the mortar with normal. Karamanoğlu and Eren [9, 10] investigate the making of mortars containing numerous amounts of crushed glass. Recycled glass and limestone filler were replaced with cement by weight. The waste glass passing was partially replaced with cement by weight at percentages of 0, 5, 10, 15, 20, 25, 30 and 40. In the end, were found in all mixes, unit weight decreases in comparison to the control mix. The crushed waste glass was successfully used for the production of many concrete mixtures. Schwarz et al. [11] and Tagnit-Hamou et al. [12–15] used the recycled glass in n concrete mixes as a partial cement replacement up to 30%. Researchers discovered advantageous properties, containing improved workability and decrease chloride permeability, via waste glass. Recycled glass concrete shows a rise in the strength capacity of concrete columns [16, 17]. Lately, a crushed waste glass of several particle-size distributions was used to improve high-strength concrete beside a compressive strength of more than 250 MPa [18]. The crushed waste glass is appropriate for use in concrete when replaced with the fine aggregate in diverse sections and it gave strengths higher than the conventional concrete [19–25]. According to the studies in using crushed waste glass in concrete, there were disagreements in the available experimental results. These disagreements involved proprieties of concrete improved with crushed waste glass. Lastly, there are limited studies on the effect of crushed glass waste material and the performance of concrete improved with crushed waste glass as fine aggregate addition.

2. Experimental parameters

In this work, the experimental investigation extended through three phases: materials, mix design and molds.

2.1. Materials

- Cement: Ordinary Portland Cement was utilized.
- Fine Aggregate: in this study sand was used as fine aggregate
- Coarse Aggregate: The gravel should be clean. 100% crushed coarse aggregate with min flat and elongated particles has been used.
- Mixing Water: Use tap water to cast and cure all the specimens.
- Glass powder: waste glass has to be ground to its powder form Before adding to the concrete mixture. In this research, glass powder milled in ball/ pulverizer for a period of (30–60) minutes lead to the particle sizes less than size 150 µm and separated in 75 µm. The glass powder is shown in (Fig. 1). Table 1 shows the grading of glass powder. The physical, chemical properties and chemical composition are presented in Table 2.

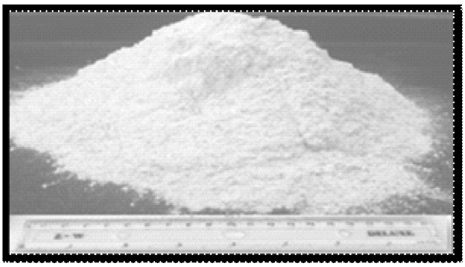

Fig. 1. Crushed Waste Glass

Table 1. Grading Crushed Waste Glass

Sieve size mm	Cumulative % passing
4.75	100
2.36	100
1.18	100
0.6	99.6
0.425	94.7
0.3	87.4
0.15	41.3
0.075	28.4
Pan	0.0

Table 2. Physical and Chemical Properties of Crushed Waste Glass

Physical Properties of Glass powder	
Relative density SG (OD)	2.41
Absorption	0%
Density (kg/m^3)	2557
Blaine surface area (kg/m^3)	3232
Chemical Properties	
pH	11.01
Colour	Grayish white
Chemical composition	**% by mass**
CaO	12.47
SiO_2	67.42
Al_2O_3	2.63
Fe_2O_3	1.47

Chemical composition	**% by mass**
MgO	2.752
Na_2O	12.31
TiO_2	0.152
ZrO_2	0.017
P_2O_5	0.053
K_2O	0.642
P_2O_5	0.053
ZnO_2	0.007
SrO	0.017
NiO	0.015
CuO	0.008
Cr_2O_3	0.024

2.2. Mix design

The concrete mixtures were proportioned to give 28-day strength of about 44 MPa based on cubes, cylinders and prisms with a slump of about 80 mm. As stated above, to reach the optimal amounts of glass powder, many trials with 5–50% glass powder as fine aggregate substitutions were prepared so that this replacement did not surpass a limit of 50%. Likewise, concrete without any mineral additions was used as the control material. Amounts of eleven concrete mixtures are given in Table 3 used in this study.

Table 3. Composition of Mixtures

No.	Mix.	Cement kg/m^3	Coarse Aggregate (Gravel) kg/m^3	Fine Aggregate (Sand) kg/m^3	Crushed Waste Glass (Fine Aggregate) kg/m^3	W/C
1	Control mix	364	980	813	0.0	0.54
2	5% Replacement	364	980	772	41	0.54
3	10% Replacement	364	980	731	72	0.54
4	15% Replacement	364	980	691	122	0.54
5	20% Replacement	364	980	650	163	0.54
6	25% Replacement	364	980	610	203	0.54
7	30% Replacement	364	980	569	244	0.54
8	35% Replacement	364	980	528	285	0.54
9	40% Replacement	364	980	488	325	0.54
10	45% Replacement	364	980	447	366	0.54
11	50% Replacement	364	980	406.5	406.5	0.54

2.3. Moulds

In each mix, nine (150 × 150 × 150) mm cubes were cast with fifteen (150 × 300) mm cylinder, and three (100 × 100 × 500) mm prisms, as shown in (Fig. 2).

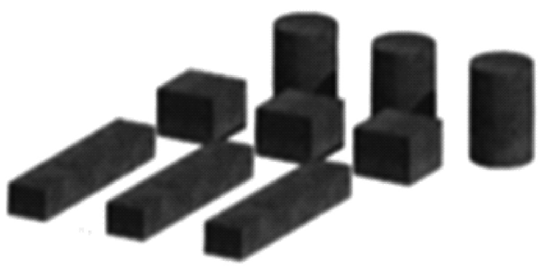

Fig. 2. Specimens of Concrete (Cylinder, Cubes, Prisms)

3. Analysis results

3.1. Workability

The objective of the slump test is to know the slump measurement for the degree of workability of the concrete after mixing. Table 4 displays how glass powder blended concrete droop esteem at distinctive percent substitution.

Table 4. Results of Slump Value Test

Mix	W/C	Slump (mm)
Control mix	0.54	87
5% Replacement Recycled Glass	0.54	67.2
10% Replacement Recycled Glass	0.54	64.5
15% Replacement Recycled Glass	0.54	61.7
20% Replacement Recycled Glass	0.54	58.3
25% Replacement Recycled Glass	0.54	55.2
30% Replacement Recycled Glass	0.54	53.2
35% Replacement Recycled Glass	0.54	50.1
40% Replacement Recycled Glass	0.54	47.5
45% Replacement Recycled Glass	0.54	44.8
50% Replacement Recycled Glass	0.54	40.2

3.2. Compressive strength

The compressive strengths of the controlled and crushed glass concrete mix at 7, 14, and 28 days are illustrated in Table 5. The comparison between the compressive strength for the same

Table 5. Average of Compressive Strength f_{cu} and f'_c (MPa) for all Mixes

Mix	Average f_{cu} Three Cubes (MPa) at ages of			Average f'_c Three Cylinders (MPa) at ages of		
	7 days	14 days	28 days	7 days	14 days	28 days
Control mix	22.2	27.13	33.31	18.87	23.12	28.34
5% Recycled Glass	26.15	33.71	36.17	22.28	28.31	30.74
10% Recycled Glass	25.21	34.81	38.52	21.25	29.61	33.75
15% Recycled Glass	25.53	29.97	40.21	21.81	25.21	34.82
20% Recycled Glass	28.72	39.61	43.80	24.82	32.81	37.82
25% Recycled Glass	24.73	30.28	40.17	21.34	25.72	33.92
30% Recycled Glass	25.3	30.01	38.61	22.08	25.21	32.91
35% Recycled Glass	26.71	29.13	36.7	22.69	24.31	31.07
40% Recycled Glass	23.1	28.51	34.12	20.61	23.51	29.21
45% Recycled Glass	20.7	25.24	33.75	16.68	21.17	28.09
50% Recycled Glass	19.31	24.35	31.21	16.12	20.21	27.5

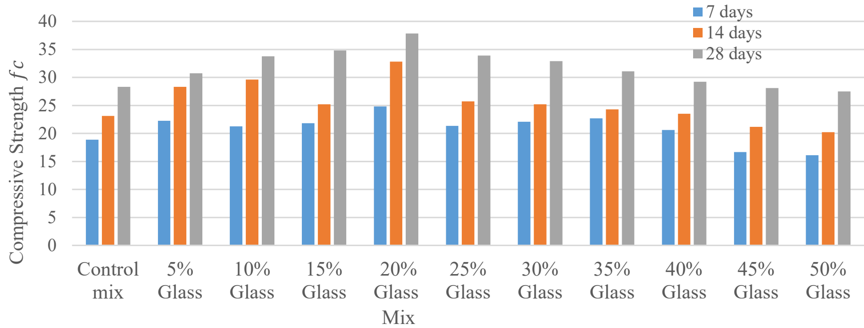

Fig. 3. Comparison Between the Cylinder Compressive Strength and Mixtures Containing Diverse Recycled Glass Replacements for Three Ages Curing

mixes is shown in (Fig. 3). It can be seen that with the addition of waste glass, Compressive strength at 28 days of concrete age becomes increases 20% and then decreases. From the results obtained, the highest 28-day compressive strength values of 43.80 MPa were found from the concrete mix of 20% replacements waste glass as fine aggregate, which signifies a rise in the compressive strength to 31% in comparison to the controlled mixture. controlled and glass aggregate mixtures display a continuous growth in strength with age. It could be detected that the percentage increases in compressive strength with age mostly increase with the addition of glass aggregate substitutions. This shows that the increase in strength improvement was found when the pozzolanic effect became important at a late age of 28 days.

3.3. Static modulus of elasticity

The modulus of elasticity of the waste glass concrete mixes at 28 days curing is presented in Table 6. From the results in Table 6, it is clearly observed that all mixes demonstrate a

Table 6. Average of Modulus of Elasticity (GPa)

Mix	Average Modulus of Elasticity (GPa) (28 days)
Control mix	26.12
5% Recycled Glass	26.61
10% Recycled Glass	27.12
15% Recycled Glass	27.4
20% Recycled Glass	28.82
25% Recycled Glass	29.27
30% Recycled Glass	29.41
35% Recycled Glass	29.63
40% Recycled Glass	29.87
45% Recycled Glass	29.98
50% Recycled Glass	30.14

continuous increase in modulus of elasticity with age, as shown in (Fig. 4). These results illustrate the better behavior for mixes containing waste glass as compared with the controlled mix. This enhancement increases with the increment of glass aggregate replacements. The results showed that the 28-day modulus of elasticity values was noticed to tend to rise over the plain mixture by 13% as the glass powder content increased to 50% replacements, as shown in (Fig. 4). These increases indicate to improved properties of these mixes. This could be ascribed to glass has a high modulus elasticity compared to natural sand.

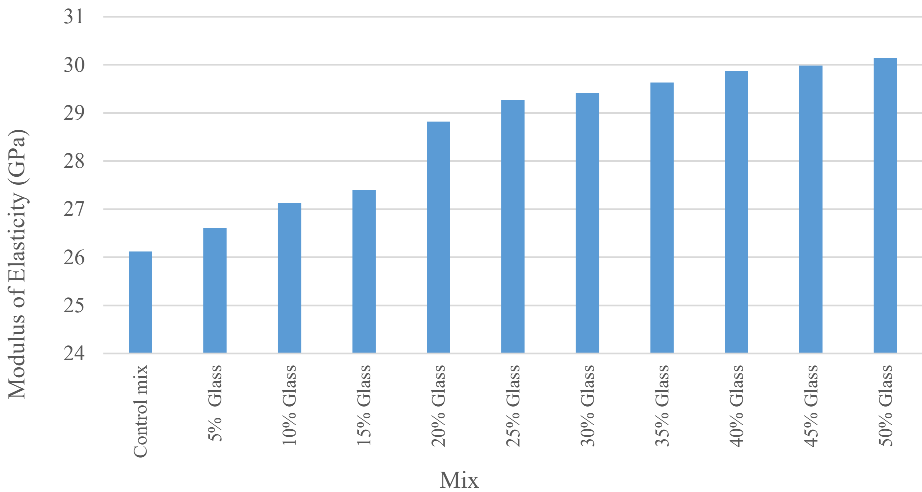

Fig. 4. Comparison Between the Modulus of Elasticity and Mixtures Containing Diverse Recycled Glass Replacements

3.4. Flexural strength

The flexural strength results at 28-day are illustrated in Table 7. Mostly, the flexural strength was detected to follow the same trend for 28-day concrete mixes. From these test results the following observations can be made:

– From Table 7, it is observed that all mixes display a continuous increase in flexural strength with age. Fig. 5 illustrates the comparison between flexural strength for mixes containing 5% to 50% of glass aggregate as partial replacements for sand and controlled mix.

– The results of flexural strength illustrate the better behavior for mixes containing waste glass as compared with the controlled mix. This enhancement increases with the increment of glass aggregate replacements, as shown in (Fig. 5). the tests showed that the 28-day flexural strength values were noticed to tend to rise over the controlled mixture by 20% as the glass powder content increased by 50% replacements.

Table 7. Average of flexural strength (MPa)

Mix	Average Flexural strength (MPa) at 28 days
Control mix	4.91
5% Recycled Glass	5.07
10% Recycled Glass	5.12
15% Recycled Glass	5.17
20% Recycled Glass	5.38
25% Recycled Glass	5.49
30% Recycled Glass	5.51
35% Recycled Glass	5.67
40% Recycled Glass	5.72
45% Recycled Glass	5.81
50% Recycled Glass	5.92

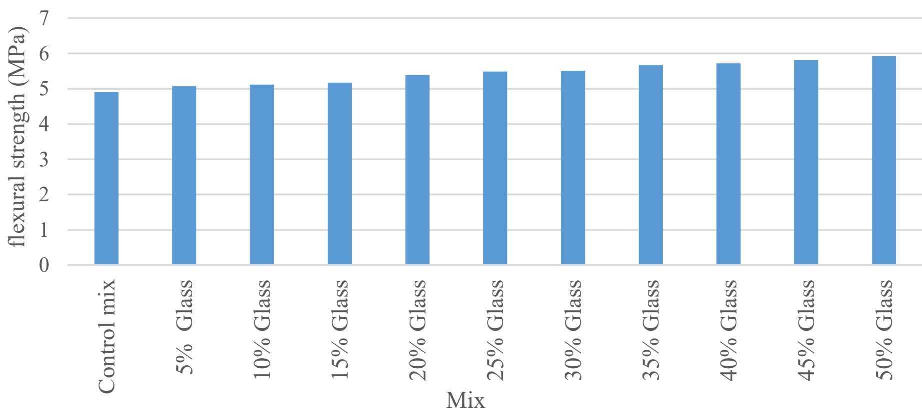

Fig. 5. Comparison Between the flexural strength and Mixtures Containing Diverse Recycled Glass Replacements

3.5. Splitting tensile strength

The splitting tensile strength for mixes after being preserved for 28 days is presented in Table 8.

From these outcomes, the following observations can be made:

– The results show development in splitting tensile strength for mixes containing waste glass replacement is higher than controlled mix with age, because of the progress of hydration and good bond strength between glass aggregate cement paste relative to controlled mix.

Table 8. Average of the Splitting Tensile Strength (MPa)

Mix	Average Splitting Tensile Strength (MPa) at 28 days
Control mix	2.527
5% Recycled Glass	2.562
10% Recycled Glass	2.72
15% Recycled Glass	2.93
20% Recycled Glass	3.14
25% Recycled Glass	3.18
30% Recycled Glass	3.24
35% Recycled Glass	3.31
40% Recycled Glass	3.38
45% Recycled Glass	3.91
50% Recycled Glass	3.98

– Based on the results, the finest 28-day splitting tensile strength value of 3.98 MPa was found from the concrete mixture of 50% glass powder fine aggregate, which signifies rise in the splitting tensile strength of 50% as compared to the controlled mixture, as shown in (Fig. 6). This performance is ascribed to the good bond strength between glass powder aggregate and the cement paste relative to bond strength between natural sand and cement paste.

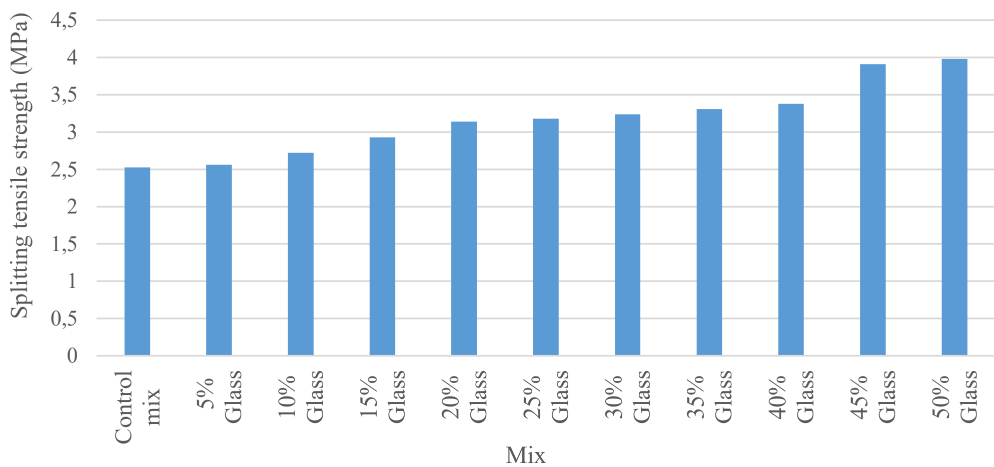

Fig. 6. Comparison Between the Splitting Tensile and Mixtures Containing Diverse Recycled Glass Replacements

3.6. Density

Air-dry densities for all mixes are shown in Table 9.

Table 9. Values of the Dry Density kg/m^3 for all Mixes

Mix	Dry Density kg/m^3 after 28 Days
Control mix	2401
5% Replacement Recycled Glass	2376.5
10% Replacement Recycled Glass	2371.7
15% Replacement Recycled Glass	2365.4
20% Replacement Recycled Glass	2361.3
25% Replacement Recycled Glass	2356.4
30% Replacement Recycled Glass	2349.7
35% Replacement Recycled Glass	2343.2
40% Replacement Recycled Glass	2337.4
45% Replacement Recycled Glass	2330.6
50% Replacement Recycled Glass	2324.9

4. Discussions and conclusions

In this context, conclusions can be summarised from the results of the experimental work as follows:

- The 7, 14 and 28 days compressive strengths of concrete rise initially as the replacement percentage of cement with crushed waste glass rise. Compressive strength at 28 days of concrete age becomes maximum at about 20% and later decreases.
- The slump of concrete containing crushed glass decreases with the increases in the glass powder content. Despite the reduction in the slump values of mixtures containing glass aggregate, they have good workability.
- The Modulus of Elasticity, the modulus of rupture and Splitting tensile strength at 28-days age of concrete rises initially as the replacement percentage of fine aggregate with crushed waste glass rises and becomes maximum at 50%.
- The slump of concrete decreases with the replacement.
- The percentage of fine aggregate with crushed waste glass rises. The workability reduces when fine aggregate is substituted partially with crushed glass.
- The unit weight of mortar was reduced with the rise in crushed glass powder percentage, due to the variance between the density of the glass powder and the aggregate.
- This study demonstrates that there is a significant potential for the use of crushed waste glass grinding concrete as a partial replacement of fine aggregate. Around 20% of fine aggregate might be substituted with crushed waste glass with no loss on the compressive strength.

– Via crushed waste glass in local construction will reduce cost significantly in the casting of one m^3 for grade concrete.

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