Fayoum University Faculty of Engineering, 2024, Vol: 7(1), 82-90
https://fuje.journals.ekb.eg/
ISSN Online: 2537-0634
ISSN Print: 2537-0626

Improving Sustainability of Concrete Using Waste Glass Powder

Shiren Osman Ahmed
Civil Engineering Department, Delta Higher Institute for Engineering & Technology, Mansoura, Egypt
*Corresponding author: Shiren Osman Ahmed (shereen@dhiet.edu.eg).

How to cite this paper: Ahmed, S.O.(2024). Improving Sustainability of Concrete Using Waste Glass Powder. *Fayoum University Journal of Engineering, Vol: 7(1), 82-90*
https://dx.doi.org/10.21608/FUJE.2023.222911.1053

Abstract

Waste glass (WG) must be recycled to produce sustainable concrete and conserve natural resources. This paper aims to study the combined influence of glass powder (GP) and glass fiber (GF) on the behavior of concrete. GP was utilized as a partial replacement of fine aggregate by (10%, 20%, and 30%) of weight. GF was added with different ratios (0, 0.4%, 0.8%, and 1.2%) of concrete volume to improve the ductility of the concrete. Many tests were performed for hardened concrete such as compressive strength, modulus of rupture, indirect tensile strength, water absorption, and dry unit weight. A slump test was performed to assess the workability of fresh concrete. The influence of GP and GF on the concrete microstructure using scanning electron microscopy (SEM) was studied. The results indicated that the mixture containing 0.8%GF, and 30%GP achieved the optimum value of compressive strength, modulus of rupture, and indirect tensile strength by 19.5%, 20%, and 22.3% with respect to the reference mix at 56 days of curing. The compressive strength of mixtures M6, M10, and M14 including 0.8%GF and GP with a ratio of 10%, 20%, and 30%, increased by 15.7%, 19%, and 19.5%, respectively at 56 days with respect to the control mix. The higher the percentage of GF, the lower the slump value. The water absorption rate of mixtures reduced as the percentage of GP increased with respect to that of the control mix. Micrographs of SEM showed the formation of crystals of calcium silicate hydrate in the concrete mixtures containing GP, this is evidence of the pozzolanic activity of the GP.

Keywords

Glass powder, Glass Fibers, Sustainability of Concrete, Scanning Electron Microscopy, Compressive Strength

1. Introduction

Large quantities of WG are buried in the land, so WG is considered a serious environmental problem. Althoey et al. [1] investigated the effect of WG as a partial replacement of sand by weight, fly ash (FA) as a partial substitution of cement, and coconut fibers (CFs) on the properties of concrete. The mixture with WG16%, FA20%, and CFs2.5% achieved the best results, where the compressive strength and flexural strength were enhanced by 15.8%, and 9.57% compared to the control mix at 90 days of curing. Samples were exposed to heat at 600 °C. The mixture with WG16% lost about 38.7% of mass and 44.2% of compressive strength, this is considered the most reduction compared to other mixes. The concrete mixtures became denser because of the presence of FA, which improved the water absorption rate of concrete. Increasing the ratio of GP above 16% of sand weight decreased the strength and durability of concrete. Tahwia et al. [2] used recycled waste glass powder (RWGP) as a partial replacement for cement and quartz powder to produce ultra-high-performance concrete (UHPC). At various ages, the mixture with 10% RWGP as a cement substitute had the best mechanical characteristics. The interfacial transition zone was greatly enhanced with the use of RWGP. The CO_2 index of RWGP50% decreased to 3.7 kg/MPa/m^3 in comparison to the reference mix which had 5.75 kg/MPa/m^3. Also, RWGP decreased the costs of production of UHPC and negative environmental effects. Elaqra et al. utilized GP as a partial substitution for cement at ratios of 0%, 10%, 20%, and 30% of weight. It was added to cement and aggregates by two methods of mixing. The first method is adding GP to cement and aggregates. The second method is dissolving GP in water before adding it to cement and aggregates. The results showed that the slump of fresh concrete rose as the ratio of GP increased. Because of the presence of extra water in mixtures which leads to a reduction in density and an increase in water absorption. The mixtures prepared with the first method of mixing had a reduction in compressive strength at an early age. At 90 days of curing, the compressive strength increased at a ratio of GP20% with respect to the control mix. The second method of mixing had high compressive strength compared with the first method of mixing. Using the second method of mixing, the compressive strength of the mixture GP10% increased by about 130% compared to that of the reference mix [3]. GP was utilized as a partial substitute for cement with different ratios ranging from 5% - 25%. Also, sand was replaced with glass sand with ratios varying between 10% and 50%. Mixtures with a combination of 10%glass sand and 5%GP had the best results in strength and durability characteristics. The penetration of chloride ions and absorption rate decreased because of the utilization of WG [4]. Garcia et al. investigated the effect of the partial replacement of cement and micro-silica by calcium carbonate and GP on the drying shrinkage of concrete. Two mixtures of UHPC with a partial replacement of cement and micro-silica were prepared and compared to the reference mix. Steel micro-fiber was added to these three mixtures by 2% of the volume of a concrete mixture. Concrete's rheological characteristics were improved by adding calcium carbonate and GP. This is leading to a reduction in the requirement for chemical additives as well as an improvement in cost-effectiveness. The drying shrinkage of UHPC and ultra-high-performance fiber-reinforced concrete decreased by a partial replacement of cement and micro-silica compared to the reference mix. Utilization of micro-fiber and dosage reduction of the cement and micro-silica reduced the drying shrinkage up to 40% with respect to the reference mix [5]. A partial replacement of cement with GP can enhance the corrosion resistance of steel in recycled aggregate concrete compared with reference mix including natural aggregates. The mixture with GP20% improved the resistance of chloride penetration without reducing the compressive strength. Adding GP to cement with low carbon can improve the durability of recycled aggregate concrete [6]. Some researchers, such as Orouji and Najaf [7] used micro-silica by 10% of cement weight and GP by 25% of fine grains weight to produce high-performance concrete. Six flexural samples and four compression samples were prepared. The samples prepared for the flexural strength test include steel, glass fiber reinforced plastic (GFRP), a hybrid of GFRP reinforcing bars with different ratios of fibers, and those without reinforcing bars. Concrete beams prepared with GFRP reinforcing bars have less flexural strength than those of steel reinforcing bars. The flexural strength of samples with steel rebars equals that of samples containing 1.5% polypropylene fibers and GFRP rebars. Thereby, reduction of the beam weight by around 4% reducing the costs of preparation and emissions of CO_2. Utilization of GFRP reinforcing bars and micro-silica reduces emissions of CO_2 by 43%, and 95.4 kg per ton of cement, respectively. Sekhar et al. [8] observed that the combination of metakaolin and GP as a partial replacement of cement and sand, respectively enhanced compressive, flexural, and splitting tensile strength. The mixture with 12% metakaolin and 10%GP achieved the best results for the mechanical properties compared with other mixes. Tamanna et al. [9] noticed an enhancement in the strength of concrete containing recycled waste glass sand as a partial replacement of natural sand and high resistance to penetration of chloride ions. Recycled waste glass sand decreased the expansion resulting from the reaction of the alkali and silica. Guo et al. [10] observed that the workability of fresh concrete increases when the content of glass particles is about 20 to 30%. In addition to that, the workability of concrete improves as the size of particles increases up to a diameter of 100 mm. Nevertheless, using coarse glass particles decreases workability. GP may improve compressive strength up to a replacement ratio of 25% of cement weight because of its pozzolanic behavior. However, using excessive glass particles could decrease the compressive strength. Moreover, glass particles can decrease concrete permeability. Orouji et al. [11] studied the improvement of ductility, and flexural and compressive strengths of concrete by using polypropylene fibers and GP. The optimum ratio of GP is 25%, which improves the concrete's compressive and flexural strengths. Additionally, a concrete mixture that contains 1.5%fibers and 25%GP has the best compressive and flexural properties. Zeybek et al.

used GP as a partial substitution for cement by 0%, 10%, 20%, 30%, 40%, and 50% of weight. In addition, three mixtures were prepared by replacing cement, fine, and coarse aggregate with GP and glass particles by 10%, 20%, and 30% of weight to investigate their combined impact on concrete behavior. The ideal dosage was GP20% as cement replacement only. Mechanical characteristics for concrete mixtures made by incorporating GP and glass particles enhanced up to the specific limit and then diminished because of poor workability. A combination of 10% GP and glass particles achieved better strength and higher workability compared with ratios of replacement 20%, and 30% [12].

2. Research Significance

There is no previous research to clarify the combined influence of adding GF with different ratios (0, 0.4%, 0.8%, and 1.2%) of concrete volume and GP as a partial replacement of fine aggregate by (10%, 20%, and 30%) of weight. This research will be extremely valuable because it can conserve natural resources up to certain limits by recycling WG, especially in developing countries. It focuses on improving the sustainability of concrete using WG. The main purpose of this research is to determine the optimal percentage of GP and GF, which gives the best test results. A Lot of tests were performed for hardened concrete such as compressive strength, modulus of rupture, indirect tensile strength, water absorption, and density. A slump test was carried out to evaluate the workability of fresh concrete. Tests results were compared in the case of using different ratios of GP and GF. The effect of GP and GF on the microstructure of concrete using SEM was studied. Moreover, the effect of adding GF to concrete mixtures on the failure mode of specimens during compressive strength test was investigated.

3. Experimental Program

3.1.Properties of Materials

Cement (C): The used cement in this research is ordinary Portland cement (CEM I 52.5 N) conforming to (EN 1974–2011). The chemical and physical properties of cement are presented in Table 1, 2.

Table 1. Physical properties of cement

Properties	Result of test
Specific area (cm²/gm)	3680
Specific gravity	3.15
Initial setting time (min)	90
Final setting time (min)	270
Compressive strength after 3 days for mortar (MPa)	20
Compressive strength after 7 days for mortar (MPa)	28.5

Table 2. Chemical properties of cement

Composition	% by weight
AL_2O_3	4.5
SiO_2	21.2
CaO	63.4
Fe_2O_3	3.3
MgO	2.72
SO_3	2.45

Aggregate: Sand was used as a fine aggregate and the natural coarse aggregate (dolomite) was utilized as a coarse aggregate in the mixtures. The characteristics of a fine and a coarse aggregate are illustrated in Table 3,4. Table 5,6 shows a sieve analysis result of a fine and a coarse aggregate.

Table 3. Characteristics of fine aggregate

Properties	
Fineness modulus	2.77
Absorption ratio	1.6%
Density (kg/m³)	1750
Specific gravity	2.56

Table 4. Characteristics of coarse aggregate

Properties	
Specific gravity	2.63
Absorption ratio	0.92%
Density (kg/m³)	1570

Table 5. Sieve analysis of fine aggregate

Sieve size (mm)	Passing %
4.75	95.2
2.36	87.5
1.18	76.3
0.6	50.4
0.3	11.5
0.15	2.1

Table 6. Sieve analysis of coarse aggregate

Sieve size (mm)	Passing %
37.5	100
20	97
10	77
4.75	6

Superplasticizer (SP): Sikament -163 was used to improve workability. It was added by (0.5%, and 1%) of cement weight conforming to ASTM C494 [13]. Table 7 shows the properties of the superplasticizer.

Table 7. Properties of superplasticizer

Characteristics	
Appearance/color	Brown liquid
Density at 20 °C (kg/l)	1.2

Glass fiber (GF): GF utilized in this experimental work are alkali resistant with a length of 12mm. Figure (1) shows GF used in the mixtures. Physical Characteristics of GF are listed in Table 8.

Figure 1. Glass fiber

Table 8. Physical Characteristics of GF

Characteristics	
Tensile strength (MPa)	2200
Aspect ratio (L/d)	80
Diameter(mm)	15
Density (g/cm^3)	2.6
Elastic modulus (GPA)	70

Glass powder (GP): Used GP passing from a sieve size of 400µm with an absorption ratio of 0.4% and density of 1745 kg/m^3. Figure (2) indicates GP utilized in concrete mixtures. The chemical components of glass powder are shown in Table 9.

Figure 2. Glass powder utilized in concrete mixtures

Table 9. Chemical components of glass powder

Chemical components	By weight%
Na_2O	14.4
Cao	12.1
Al_2O_3	2.56
SiO_2	66
MgO	1.92
Fe_2O_3	0.8
SO_3	0.14
K_2O	0.98
P_2O_3	0.15

3.2.Mix Design and Proportions

In this research, recycled GP was washed to get rid of impurities, grinded, and then it was sieved on a sieve size of 400µm. GP was utilized as a partial replacement of fine aggregate by (10%, 20%, and 30%) of weight. The ratio of water to cement (W/C) was 0.35. GF was used with different ratios (0, 0.4%, 0.8%, and 1.2%) of concrete volume. The proportions of the concrete mix were designed according to ACI 211 [14]. Fifteen concrete mixtures including GP and GF were prepared and compared with the reference mix. Table 10 presents mix proportions (Kg/m3) of concrete.

Table 10. Mix proportions (Kg/m^3) of concrete

Name	GF%	GP%	GP	C	C.A	F.A	SP	W
NC GF0GP0	0	0	0	400	1268	634	2	140
M1 GF0.4GP0	%0.4	0	0	400	1268	634	4	140
M2 GF0.8GP0	%0.8	0	0	400	1268	634	4	140
M3 GF1.2GP0	%1.2	0	0	400	1268	634	4	140
M4 GF0GP10	0	10%	63.4	400	1268	570.6	4	140
M5 GF0.4GP10	%0.4	10%	63.4	400	1268	570.6	4	140
M6 GF0.8GP10	%0.8	10%	63.4	400	1268	570.6	4	140
M7 GF1.2GP10	%1.2	10%	63.4	400	1268	570.6	4	140
M8 GF0GP20	0	20%	126.8	400	1268	507	4	140
M9 GF0.4GP20	%0.4	20%	126.8	400	1268	507	4	140
M10 GF0.8GP20	%0.8	20%	126.8	400	1268	507	4	140
M11 GF1.2GP20	%1.2	20%	126.8	400	1268	507	4	140
M12 GF0GP30	0	30%	190	400	1268	444	4	140
M13 GF0.4GP30	%0.4	30%	190	400	1268	444	4	140
M14 GF0.8GP30	%0.8	30%	190	400	1268	444	4	140
M15 GF1.2GP30	%1.2	30%	190	400	1268	444	4	140

4. Results and Discussion

4.1. The Workability of Fresh Concrete

The workability of fresh concrete was investigated using a slump test in accordance with ASTM C143/C143M-20 [15]. It was noticed from Figure (3) that the slump value reduced for all mixtures compared to that of the control mix. The higher the percentage of GF, the lower the slump value. This can be explained to the large surface area of GF; they need excess water to cover them which leads to a reduction in mixing water. Moreover, GF causes higher internal friction for the components of the concrete mixture causing a decrease in workability [16,17]. The addition of a superplasticizer reduced the decline of slump values. A very small reduction in slump values was noticed (Reduction -2.9%, -1.4%, and -4.3%) for M4, M8, and M12, respectively compared to the control mix.

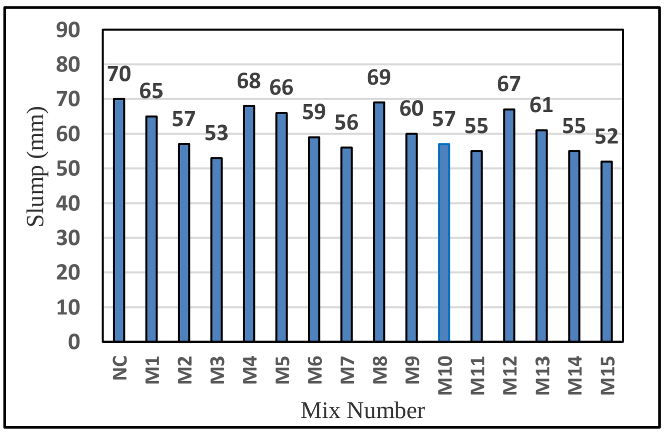
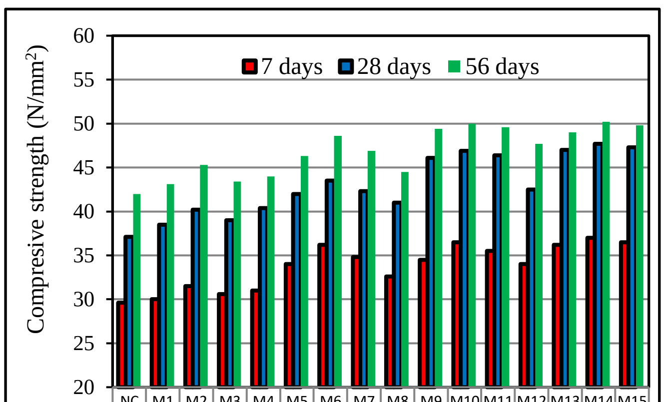


Figure 3. Workability of fresh concrete mixtures

4.2. The Compressive Strength

Compression cubic specimens with dimensions of 15 x 15 x 15 cm were tested after 7-, 28-, and 56-day ages [18]. The results of compressive strength for different mixtures are indicated in Figure (4). It was noticed that compressive strength increased with the increased ratio of GP compared to that of the control mixture. This is consistent with other studies [11]. This is due to the presence of a high percentage of silica (SiO_2) in the GP, which interacts with calcium hydroxide (CH) produced from cement hydration. As a result, calcium silicate hydrate (C-S-H) is formed, which appears in the form of crystals and fills the voids, this leads to an increase in adhesion to the cement mortar. Also, it was observed that the compressive strength of the mixtures including GP and GF increased by increasing the percentage of GF compared to that of the control mixture, and it achieved its maximum value at 0.8%GF and then decreased at a ratio of 1.2%GF. The reason for this increase is that the GF makes confinement of the concrete, which leads to an increase in the cohesion of the concrete. The compressive strength for mixtures containing only GF such as M1, M2, and M3, increased with a ratio of 3.8%, 8.4%, and 5.1% at the age of 28 days and with a percentage of 2.6%, 7.86%, and 3.3%, respectively at the age of 56 days compared to that of control mixture. Many authors have confirmed these observations [19]. The mixture M14 containing 0.8%GF, and 30%GP achieved the maximum value of compressive strength, it increased by 19.5% compared to that of the reference mix at 56 days. The compressive strength of mixtures M6, M10, and M14 including 0.8%GF and GP with a ratio of 10%, 20%, and 30%, respectively, increased by 15.7%, 19%, and 19.5%, respectively at 56 days with respect to the control mixture. The compressive strength for mixtures M4, M8, and M12 has risen by 4.8%, 5.95%, and 13.6%, respectively at 56 days of curing compared with that of the control mix. Figure (5) indicates the failure mode of the specimens NC and M14 during the compressive strength test. It was observed sudden and typical collapse in NC while the addition of GF in mixture M14 prevented the occurrence of a complete collapse of the specimen and reduced cracks. This agrees with previous studies [11]. The addition of GF converts the behavior of concrete from brittleness to ductility. This matches with the results of compressive strength where the M14 specimen had the maximum compressive strength value.



	NC	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15
7 days	29.6	30	31.5	30.6	31	34	36.2	34.8	32.6	34.5	36.5	35.5	34	36.2	37	36.5
28 days	37.1	38.5	40.2	39	40.4	42	43.5	42.3	41	46.1	46.9	46.4	42.5	47	47.7	47.3
56 days	42	43.1	45.3	43.4	44	46.3	48.6	46.9	44.5	49.4	50	49.6	47.7	49	50.2	49.8

Mix Number

Figure (4). Compressive strength for different mixtures at 7, 28, and 56 days of curing

Figure 5. The failure mode for the control specimen (NC) and M14 during the compressive strength test

4.3. The Modulus of Rupture

The modulus of rupture test was carried out for all mixtures on concrete beams with dimensions of 10×10×50 cm at 7, 28, and 56 days of curing [20, 21]. The findings of the modulus of the rupture test are illustrated in Figure (6). It was observed that the modulus of rupture for all mixtures agrees with the compressive strength. The values of the modulus of rupture for the different mixtures containing GP and GF improved with increasing the percentage of GP. The modulus of rupture for mixtures M4, M8, and M12 increased by 1.7%, 5%, and 11.7%, respectively at 56 days with respect to that of the reference mix (NC). The mixture M14 had the maximum value of the modulus of rupture compared with other mixtures. Moreover, the modulus of rupture for the mixtures containing GP and GF enhanced by increasing the ratio of GF compared to that of the control mixture. The modulus of rupture achieved a maximum value at 0.8%GF, then it decreased at a ratio of 1.2%GF. The modulus of rupture for mixtures M1, M2, and M3 including only GF increased by 8.3%, 13.3%, and 3.33%, respectively with respect to the reference mix at 56 days of curing. Previous research agrees with this finding [17,22,27]. The modulus of rupture for mixtures M6, M10, and M14 containing 0.8%GF and GP with a ratio of (10%, 20%, and 30%) increased by 15%, 16.7%, and 20%, respectively with respect to reference mix at 56 days of curing. This matches with various studies [11].

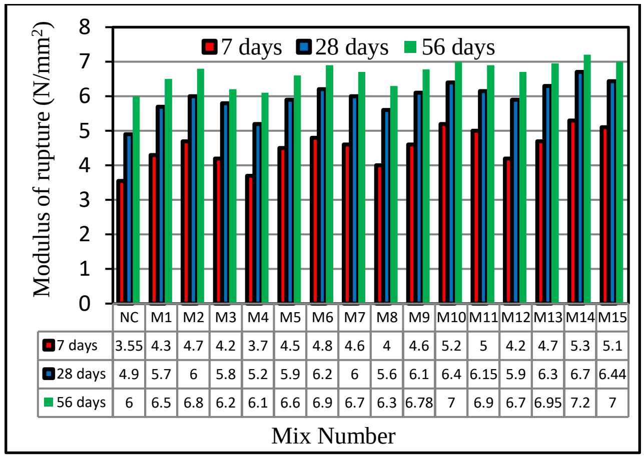


Figure 6. Modulus of rupture for different mixtures at 7, 28, and 56 days of curing

4.4. The Indirect Tensile Strength

The indirect tensile strength test was performed on concrete cylinders with dimensions of 15 × 30 cm after 7-, 28-, and 56-days ages [23]. Three samples for each age were used. Figure (7) indicates the findings of the indirect tensile strength for all mixtures. The indirect tensile strength for mixtures M1, M2, and M3 increased by 3.7%, 11.7%, and 6.4%, respectively compared to that of the control mix at 56 days of curing. There is agreement from many researchers on this result [17,22]. The indirect tensile strength for mixtures M6, M10, and M14 improved by 14.8%, 19.7%, and 22.3%, respectively with respect to that of the control mix at 56 days of curing. It increased by increasing the ratio of GF and GP. The optimum value of indirect tensile strength was at a ratio of 0.8%GF. The indirect tensile strength for mixtures M4, M8, and M12 increased by 4.5%, 9%, and 14.4%, respectively at 56 days compared to that of the reference mix. It was noticed that the indirect tensile strength had the same path as compressive strength and modulus of rupture.

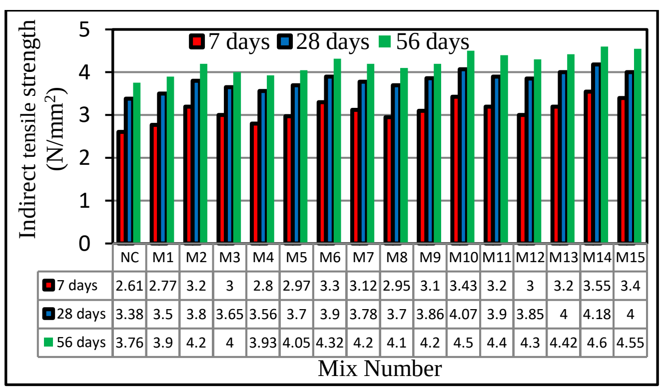


Figure 7. Indirect tensile strength for different mixtures at 7, 28, and 56 days of curing

4.5. The Water Absorption

To determine the rate of water absorption for different mixtures, cubic samples with dimensions of 10×10×10 cm were used after 56 days of curing conforming ASTM C642 [24]. The results of the water absorption test for various mixtures are shown in Figure (8). It was noticed that the water absorption rate of mixtures containing GP and GF reduced as the percentage of GP increased compared to that of the reference mix. This is due to the production of C-S-H by the pozzolanic behavior of GP, which leads to filling the voids and enhancing the concrete mixture microstructure. The higher the ratio of GF, the lower the rate of water absorption. Because of the increment adhesion of the GF with the concrete. Previous research is consistent with this finding [17,25]. It was observed a reduction in the rate of water absorption for mixtures M4, M8, and M12 by 13.9%, 27.9%, and 40%, respectively. The rate of water absorption for mixtures M1, M2, and M3 decreased by 1.16%, 4.65%, and 9.3%, respectively. Also, it diminished by 20.9%, 33.9%, and 46.5% for mixtures M6, M10, and M14, respectively.

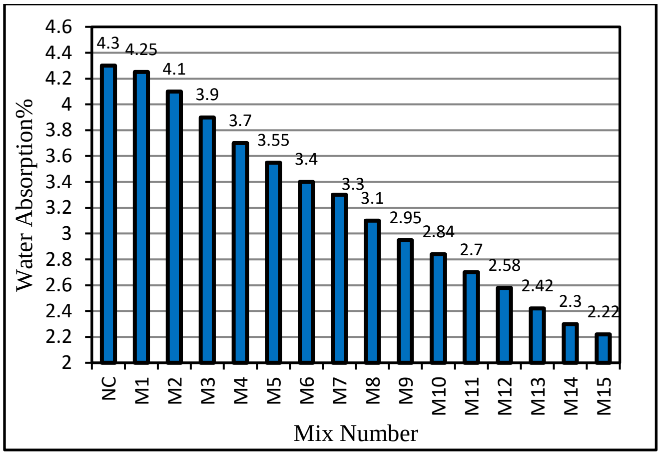


Figure 8. The rate of water absorption for various mixtures after 56 days of curing

4.6. The Dry Unit Weight

The dry unit weight test was performed on cubic specimens with dimensions of 10×10×10 cm at 56 days of curing according to BS 1881 [26]. Figure (9) illustrates that there was an increase in dry unit weight for all mixtures containing GP and GF compared to that of the control mixture. The dry unit weight increased with increasing the ratio of GP. Because of the formation of C-S-H resulting from the presence of active silica in GP which fills pores. The dry unit weight of mixtures M4, M8, and M12 increased by 1.5%, 2.66%, and 3.5%, respectively with respect to that of the reference mix. The decrease in water absorption is connected to the rise in the dry unit weight of concrete. The dry unit weight increased as the ratio of GF increased because the presence of GF increases the cohesion with concrete and makes concrete denser. There was an increment of dry unit weight for mixtures M1, M2, and M3 by 0.2%, 0.5%, and 1.02%, respectively compared to that of NC. A lot of researchers agree with this explanation [17,27].

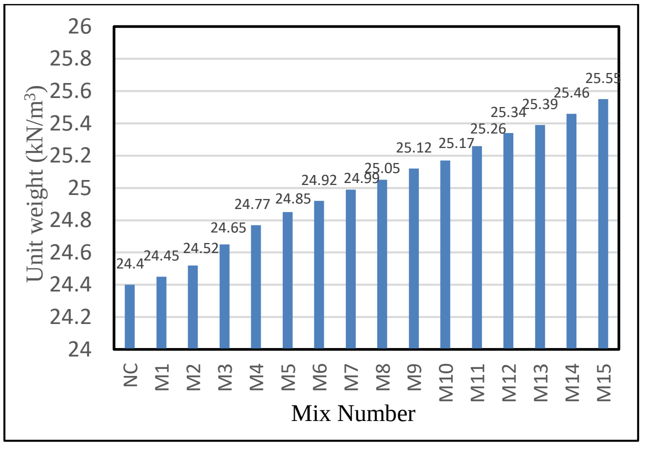


Figure 9. The dry unit weight for different mixtures at 56 days of curing

4.7. Scanning Electron Microscopy

SEM was utilized after 56 days of curing to determine the effect of GP and GF on microstructure. By analyzing the microstructure, it can be precisely evaluated mechanical and physical characteristics of concrete. Figure (10) indicates micrographs of SEM. It was observed that the control mix (NC) had a lot of pores. Also, it was noticed in the mixture M1 containing only GF that the GF is uniformly distributed and has good adhesion with cement mortar. Furthermore, the micrographs of the mixtures M12, and M14 show the formation of crystals of calcium silicate hydrate which fill the voids. This may be due to the presence of a high ratio of active silica in GP. Therefore, an increase in compressive strength and good adhesion to the cement mortar. The formation of calcium silicate hydrate is evidence of the pozzolanic activity of GP [2,11,17].

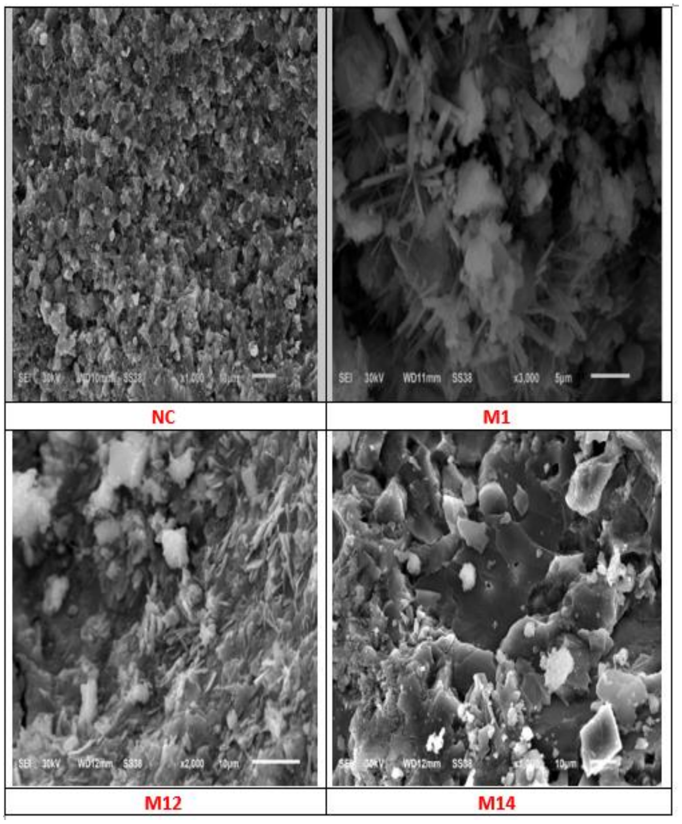


Figure 10. Micrographs of SEM for NC, M1, M12, and M14 after 56 days

5. Conclusions

The impact of GP and GF on the physical and mechanical properties of concrete was studied. From the findings of the experiments, it is possible to conclude the following conclusions: -

1. The compressive strength increased with the increased ratio of GP with respect to that of the reference mix. The compressive strength of the mixtures including GP and GF increased by increasing the percentage of GF compared to that of the control mix, and it achieved its maximum value at 0.8%GF. The mixture M14 containing 0.8%GF and 30%GP achieved the optimum value of compressive strength, it increased by 19.5% compared to that of the reference mix at 56 days. The addition of GF by 0.8% in mixture M14 prevented the occurrence of a complete collapse of the specimen and reduced cracks.

2. The modulus of rupture for all mixtures agrees with compressive strength. The modulus of rupture for mixtures M1, M2, and M3 containing GF only increased by 8.3%, 13.3%, and 3.33%, respectively with respect to the reference mix at 56 days of curing. The modulus of rupture for mixtures M6, M10, and M14 containing 0.8% GF and GP with a ratio of (10%, 20%, and 30%) increased by 15%, 16.7%, and 20%, respectively with respect to the reference mix at 56 days of curing.

3. The indirect tensile strength has the same path as compressive strength and modulus of rupture. The indirect tensile strength for all mixtures increased with an increasing ratio of GF and GP and the maximum value of indirect tensile strength was at a ratio of 0.8%GF. The indirect tensile strength for mixtures M6, M10, and M14 improved by 14.8%, 19.7%, and 22.3%, respectively with respect to the reference mix at 56 days of curing.

4. The water absorption rate of mixtures containing GP and GF reduced as the percentage of GP rose with respect to that of the control mix. The higher the ratio of GF, the lower the water absorption rate due to the increment adhesion of the GF with the concrete. The rate of water absorption for mixtures M1, M2, and M3 decreased by 1.16%, 4.65%, and 9.3%, respectively. Also, it diminished by 20.9%, 33.9%, and 46.5% for mixtures M6, M10, and M14, respectively.

5. The dry unit weight for all mixtures containing GP and GF. The dry unit weight increased with increasing the ratio of GP. The dry unit weight of mixtures M4, M8, and M12 increased by 1.5%, 2.66%, and 3.5%, respectively with respect to that of the reference mix.

6. The workability reduced for all mixtures compared to that of the control mixture. The higher the percentage of GF, the lower the slump value. A very small reduction in slump values was noticed (Reduction-2.9%, -1.4%, and -4.3%) for M4, M8, and M12, respectively compared to control mix.

7. SEM micrographs showed that GF is uniformly distributed and has good adhesion with cement mortar. Moreover, the formation of crystals of calcium silicate hydrate in the mixtures containing GP fills the voids. This is evidence of the pozzolanic activity of the GP.

References

[1] Althoey, F., Zaid, O., Majdi. A., Alsharari, F., Alsulamy, S., & Arbili, M.M. (2023). Effect of Fly Ash and Waste Glass Powder as A Fractional Substitute on The Performance of Natural Fibers Reinforced Concrete. Ain Shams Engineering Journal. https://doi.org/10.1016/j.asej.2023.102247

[2] Tahwia, A. M., Essam, A., Tayeh. B. A., & Abd Elrahman, M. (2022). Enhancing Sustainability of Ultra-High-Performance Concrete Utilizing High-Volume Waste Glass Powder. Case Studies in Construction Materials,17, e01648. https://doi.org/10.1016/j.cscm.2022.e01648

[3] Elaqra, H. A., Abou Haloub, M. A., & Rustom, R.N. (2019). Effect of New Mixing Method of Glass Powder as Cement Replacement on Mechanical Behavior of Concrete. Construction and Building Materials, 203, 75-82. https://doi.org/10.1016/j.conbuildmat.2019.01.077

[4] Baikerikar, A., Mudalgi, Sh., & Ram, V. V. (2023). Utilization of Waste Glass Powder and Waste Glass Sand in The Production of Eco-Friendly Concrete. Construction and Building Materials, 377, 131078. https://doi.org/10.1016/j.conbuildmat.2023.131078

[5] Garcia, J. A., Khan, M. I., Abbas, Y. M., Lir´on, V. M., & Mu˜noz, J. S. C. (2023). The Drying Shrinkage Response of Recycled-Waste-Glass-Powder-and Calcium-Carbonate-Based Ultrahigh-Performance Concrete. Construction and Building Materials, 379, 131163. https://doi.org/10.1016/j.conbuildmat.2023.131163

[6] Peng, L., Zhao, Y., Ban, J., Wang, Y., Shen, P., Lu, J. X. & Poon, Ch. S. (2023). Enhancing The Corrosion Resistance of Recycled Aggregate Concrete by Incorporating Waste Glass Powder. Cement and Concrete Composites, 137, 104909. https://doi.org/10.1016/j.cemconcomp.2022.104909

[7] Orouji, M., & Najaf, E. (2023). Effect of GFRP Rebars and Polypropylene Fibers on Flexural Strength in High-Performance Concrete Beams with Glass Powder and Micro-silica. Case Studies in Construction Materials, 18, e01769. https://doi.org/10.1016/j.cscm.2022.e01769

[8] Sekhar, M. Ch., Kumar, M. H., Raju, S. L., & Saikrishnamacharyulu, I. (2023). Influence of Metakaolin and Glass Powder on Mechanical Behaviour of Concrete. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.03.713

[9] Tamanna, N., Tuladhar, R., & Sivakugan, N. (2020). Performance of Recycled Waste Glass Sand as Partial Replacement of Sand in Concrete. Construction and Building Materials,239, 117804. https://doi.org/10.1016/j.conbuildmat.2019.117804

[10] Guo, P., Meng, W., Nassif, H., Gou, H., & Bao, Y. (2020). New Perspectives on Recycling Waste Glass in Manufacturing Concrete for Sustainable Civil Infrastructure. Construction and Building Materials,257, 119579. https://doi.org/10.1016/j.conbuildmat.2020.119579

[11] Orouji, M., Zahrai, S. M., & Najaf, E. (2021). Effect of Glass Powder & Polypropylene Fibers on Compressive and Flexural Strengths, Toughness, and Ductility of Concrete: An Environmental Approach. Structures,33, 4616-4628. https://doi.org/10.1016/j.istruc.2021.07.048

[12] Zeybek, O., Özkılıç, Y. O., Karalar, M., Çelik, A. I., Qaidi, Sh., Ahmad, J., Nergis, D. D. B., & Nergis, D. P. B. (2022). Influence of Replacing Cement with Waste Glass on Mechanical Properties of Concrete. Materials,15, 7513. https://doi.org/10.3390/ma15217513

[13] ASTM C494 / C494M-19, Standard Specification for Chemical Admixtures for Concrete, ASTM International, West Conshohocken, PA, 2019.

[14] American Concrete Institute. Committee 211. Recommended Practice for Selecting Proportions for Normal and Heavy Weight Concrete (ACI 211.1-77). Detroit.

[15] ASTM C143 / C143M-20, Standard Test Method for Slump of Hydraulic-Cement Concrete, ASTM International, West Conshohocken, PA, 2020.

[16] Ahmad J., Manan A., Ali A., Khan M.W., Asim M., & Zaid O. (2020). A Study on Mechanical and Durability Aspects of Concrete Modified with Steel Fibers (SFs). Civ. Eng. Arch, 8, 814–823. doi: 10.13189/cea.2020.080508.

[17] Ahmad, J., Lezcano, R. A. G., Majdi, A., Ben Kahla, N., Deifalla, A.F., & El-Shorbagy, M. A. (2022). Glass Fibers Reinforced Concrete: Overview on Mechanical, Durability and Microstructure Analysis. Materials, 15, 5111. https://doi.org/10.3390/ma15155111

[18] ISO 1920 Concrete Tests-Dimensions, Tolerances, and Applicability of Test Specimens.

[19] Sivakumar, A., & Santhanam, M. (2007). Mechanical Properties of High Strength Concrete Reinforced with Metallic and Non-Metallic Fibers. Cem. Concr. Compos., 29, 603–608. https://doi.org/10.1016/j.cemconcomp.2007.03.006

[20] ISO 4012 Concrete-Determination of Compressive Strength of Test Specimens.

[21] ISO 4013 Determination of Flexural Strength of Test Specimens.

[22] Vignesh, P., Krishnaraja, A.R., & Nandhini, N. (2014). Study on Mechanical Properties of Geo Polymer Concrete Using M-Sand and Glass Fibers. Int. J. Innov. Res. Sci. Eng. Technol., 3, 110.

[23] BS-1881 Testing Concrete, Part 117 Method of Determination of Tensile Splitting Strength.

[24] ASTM C642. Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. Philadelphia (PA): ASTM; 2001.

[25] Sivakumar, V., Kavitha, O., Arulraj, G.P., & Srisanthi, V. (2017) An experimental Study on Combined Effects of Glass Fiber and Metakaolin on The Rheological, Mechanical, and Durability Properties of Self-Compacting Concrete. Appl. Clay Sci, 147, 123–127. http://dx.doi.org/10.1016/j.clay.2017.07.015

[26] BS 1881. Part 114 Methods for determination of density of hardened concrete.

[27] Chen, H., Wang, P., Pan, J., Lawi, A.S., & Zhu, Y. (2021). Effect of Alkali-Resistant Glass Fiber and Silica Fume on Mechanical and Shrinkage Properties of Cement-Based Mortars. Constr. Build. Mater., 307, 125054. https://doi.org/10.1016/j.conbuildmat.2021.125054