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Experimental Investigation of Mechanical Properties and Durability of Sustainable Concrete Using Glass Waste

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Abstract

This research aims to study some of the properties of concrete containing with glass wastes in the fresh state and the hardened state. Concrete mixtures containing glass waste powder (GP) with size less than 0.075 mm as an addition to the cement weight by 10%, 20% and 30%, glass waste fine aggregate (GF) passed through a 1.18 mm Sieve as a partial replacement of sand with the same ratios and also make a concrete mixture containing GP and GF together at a ratio of 20%. Chemical additions and mineral additives were used by 0.6% and 5% of the weight of the cement materials respectively. The results of the research showed that specimens with glass waste have a better workability compared to the control mixture. The compressive strength (f_c) of the control mixture reaches 43 Mpa, at the age of 28 days for GF, there is an improvement in f_c up to 5% at 10%, above this ratio the strength decreased compared to the control mixture. For GP, there is a decrease in f_c compared to the control mixture at all ratios. While at the age of 56 day, there is an increase in f_c of GF concrete up to 24.7% and 11.6 at 10% and 20%, respectively, then after which there was a decrease in f_c compared to the control mixture. For GP, there is an increase in f_c reached 3%, 6.5% at the percentage of addition 10%, 20%, respectively, then a decrease occurred compared to the control mixture. The indirect tensile strength (f_t) of the control mixture reaches 3.98 Mpa, f_t of GP and GF concrete decreases significantly, reaching 113% and 98%, respectively, compared to the control mixture. For Specimens with GP and GF together with ratio 20%, it was found that there a decrease in f_c and f_t compared to the control mixture. The porosity and absorption of GP and GF concrete increased by an average of 70% and 90% compared to the control mixture, respectively. The density of GP and GF concrete is lower compared to the density of the control mixture.

Keywords*—Glass Waste, Glass powder, Sustainability, Green Environment, Compressive Strength, Tensile Strength, Absorption and Porosity.*

1. Introduction

Concerning sustainable green environment, protection of natural resources and production of more effective materials, the use of waste in concrete has now become a global trend for waste management (Olofinnade OM, Ndambuki JM, Ede AN, Booth C, 2017). Waste glass is one of the best materials to replace natural sand because both waste glass and natural sand are similar in many of their physical properties (Gerges N. N et al., 2018). Waste glass able to improve the fresh concrete properties as it has smooth surface and low water absorption that can influence the workability of concrete (Pratheba S et al., 2018). The reuse of glass waste in concrete results in some economic and environmental benefits. Replacing part of the conventionally concrete materials in certain proportions reduces the cost of concrete production and reduces pollution resulting from the mining of raw materials. On the other hand, preserve the natural resources of the sources of concrete aggregates (M.S.M. Al-kahtani et al., 2022; Sharma R, 2022).

As waste glass has high amounts of amorphous silica in itself, which is necessary for pozzolanic reactivity, many studies have used powder and glass fines as a partial replacement for cement and aggregate in the production of geopolymer concrete. This novel technique reduces the cost of concrete production and reduces the amount of CO_2 emission and its adverse effect on the environment during the production of cement. This technique reduces the amount of waste glass. This technique reduces the quantities of glass and thus can be disposed of in nature (P. Guo et al., 2020; S. Chandra Paul, B. Savija, and A. J. Babafemi, 2018). Topcu l. and Canbaz, M. (Topcu l. and Canbaz, M.,

2004) use of waste glass powder in concrete as an aggregate has some problems because of the interaction between the alkali in the cement and the silica glass. The interaction of alkali with silica results in a gel (GEL), which in turn will swell in the presence of moisture, causing cracks and damage to concrete. This reaction can occur in ordinary concrete if the natural aggregate contains a large amount of silica.

The research showed a number of solutions to the phenomenon of interaction of alkali with silica and confirmed that it is a problem that shows its drawbacks in the long term and from these solutions, Grinding the glass more smoothly, Replacing part of the cement with k]aolin, due to the ability of kaolin to absorb ions, thus reducing the interaction between alkali and silica, Processes of coating glass particles with an effective coating that prevents the interaction of silica glass with cement alkalis and Modifying the chemical composition of the glass, as the results of the research showed the use of green glass, which contains chromium oxide, which gives it a green color, and does not cause a reaction between aggregates and alkalis.(lsmail, Z. and Al-Hashmi,E., 2009) **i**nvestigated the properties of concrete containing glass waste as part of fine aggregate at rates (10%, 15%, and 20%), and The results of compressive strength and flexural strength of samples containing (20%) of glass waste were higher compared to the reference mixture (ordinary sand) by (4.23%, 10.99%), respectively. (R.Vandhiyan et al., 2013) **t**he workability of mixtures containing glass powder instead of cement in different proportions was studied. The results showed that the workability decreased with the increase in the percentage of glass powder replacement with cement, and this is due to the increase in the surface area of the glass powder as well as the angular shape of the glass particles. (Vasudevan Gunalaan and Kanapathy pillay Seri Ganis) the compressive strength of the samples containing waste glass powder as a partial substitute for cement was studied at the ages of 7, 14 and 28 days of treatment.

The results showed that the mixture containing 20% glass powder showed a positive value of compressive strength at 28 days compared to other mixtures that could not be achieved at 15% and 10% although there was a slight increase from the results of 14 days. (Khatib J.M. et al) studied the performance of concrete as partial replacement of cement and concluded that the maximum compressive strength occurs at around 10% glass Powder and beyond 10% it tends to decrease and is lower than that of control. (Z.Kalakada and J.H. DOH, 2018) studied the use of recycled glass waste powder (GP) as pozzolan cement (concrete binder). Two particle sizes of 75 µm and 150 µm were used for the study. The GP replacement percentages in the study were 0% and 20%. %, 40%, 60% and 80% of the weight of the cement. The workability, density, compressive and tensile strength were examined.The test results showed that GP as a replacement percentage of the weight of the cement is used in low strength and light weight applications. In addition, GP can be used in places where there is a higher demand for workability GP concrete can become a sustainable option for the industry. (Sadoon Abdallah, Mizi Fan, 2014) the properties of concrete containing finely crushed glass were studied during its process. The workability of fresh concrete, unit weight, compressive strength, cleavage tensile strength, flexural strength, modulus of elasticity, ultrasonic pulse velocity, dry density, water absorption and alkali silica reaction (ASR) were examined. When using the content of glass waste in proportions (0%, 5%, 15% and 20%) at different treatment ages of 7, 14 and 28 days. The study showed that the workability of concrete containing glass waste as an alternative to fine aggregate decreased with the increase in the content of glass waste, but without loss in workability.

The results showed that the compressive, indirect tensile and flexural strengths of concrete containing 20% of glass waste instead of fine aggregate increased by 5.28%, 18.38% and 8.92%, respectively, at the age of 28 days. The results using the evaluation of the ultrasonic pulse velocity showed that the waste glass mixtures have a high internal density of the concrete structure. The results show that there is a clear decrease in water absorption by increasing the percentage of glass waste aggregates, and a clear decrease in the expansion of the glass waste concrete resulting from the alkaline silica reaction that occurs between the active silica of the glass waste and the alkali in the cement. (Erfan Najaf and Hassan Abbasi, 2022) in this research compacted concrete samples were produced using waste glass powder, waste plastic powder, micro-silica, .fly ash, and recycled powdered concrete. In extremely small quantities, glass powder may be used to replace cement, and in greater quantities, it can take the place of aggregate. It was found that completely recycled concrete can be obtained using recycled materials such as glass, plastic and recycled concrete and that only 20% of the weight of cement could be used without lowering the compressive and .flexural strength of the concrete. Most studies have shown a decrease in water absorption ranging from 25% to 72% when we replace part of the sand with glass waste by a rate ranging from 40% to 70% (J.-X. Lu et al., 2019; K.I.M. Ibrahim, 2017).

(Anand B Zanwar and Yogesh D Patil1, 2021) the effect of waste glass powder (WGP) replacement of cement weight on the workability of concrete and the mechanical properties included in density, strength activity index and compressive strength was studied. The results showed that the use of waste glass powder (WGP) by 20% as a substitute for cement in concrete cubes increases the strength by about 12.5%. In addition, the use of WGP up to 20% improves the properties of concrete. However, the workability of concrete decreases when replacing WGP, due to the finer surface area of the waste glass powder. A study was conducted on the effect of using crushed glass waste powder (GP) as a substitute for cement on the properties of concrete. Laboratory tests were performed with (0, 15, 18, 21, 24, 27, and 30%) partial substitution of cement with the powder of the ground waste glass to determine the strength activity index, workability, splitting and compression properties of the concrete. The results showed that by increasing the percentage of glass content, the workability decreased.

While the compressive strength of concrete is significantly improvement occurs at 21% cement substitution. However, as increasing the glass content, the indirect tensile strength decreases. The results clearly showed that the moderate strength of sustainable concrete can be produced using 20% glass powder as an alternative for structural applications (Olofinnade OM, Ndambuki JM, Ede AN, Booth C, 2017)**]**. A study was conducted to determine the optimal percentage of glass waste to increase the strength of hardened concrete such as compressive strength and split tensile strength. The replacement percentage of the waste glass in the concrete are 0%, 10%, 20%, 30%. Environmental issue has increase due to large amount of waste glass disposal at the landfills. This study is important as it can help to decrease the percentage of overall glass waste in the landfill area thus led to the decrease of waste disposal (Yang S, Lu J X and Poon C S., 2021**)**. Observations of XRD analysis of mortars with cement replaced by different amounts of GP and without GP have shown that the calcium hydroxide content in mortars with GP is reduced and when cement replacement is more than 30%, insufficiency of calcium hydroxide for the pozzolanic reaction of GP is more obvious. And when the percentage of cement replacement is more than 30%, we notice a more obvious lack of calcium hydroxide for the pozzolanic reaction of glass powder (Hongjian Du, Kiang Hwee Tan, 2017; Zh.u. Pan et al., 2017).

2. The aim of this Study

The main objectives of the study can be summarized in the following points:

- Studying the effect of adding waste glass on the properties of fresh concrete (workability).
- Studying the effect of adding waste glass on the properties of hardened concrete (compressive strength, indirect tensile strength, porosity, absorption, density).

3. Study Plan

In order to reach the research objectives, this study was divided into several stages as follows:

- Gathering the necessary information and data related to the subject by reviewing some previous studies.
- Developing a sufficient practical program to complete this study, where the glass waste was collected, grinded, smoothed and sieved to obtain glass with specifications that can be used as an addition to cement and fine aggregate, and the approval of other used materials (cement, sand, gravel) and their specifications, and the preparation of molds and cylinders used for this study Preparing the concrete mixtures required for this study and conducting the required tests on them.
- Writing down the results obtained, analyzing them, and making the necessary recommendations.

4. Experimental Study

4.1 Used Materials:

Dolomite aggregate, supplied from approved quarries in Egypt, was used, and the maximum nominal size of 14 mm was used for all study mixtures. The reason for using this size is that it helps in operation, and also because it was used successfully in previous research. Table (1) shows tests to determine the physical and mechanical properties of dolomite aggregates, and Figure (1) shows the sieve analysis of dolomite. The sand used in this study is natural sand supplied from approved quarries in Egypt, and laboratory tests were conducted on it. Figure (2) shows the grading curve for the used sand, and Table (2) shows the natural properties of the used sand. The water used in the concrete mixtures in this study is potable water, and water was added to all the mixtures in this study as a constant percentage of the weight of the cement (W/C = 0.5). The cement used in concrete mixes was ordinary Portland cement (CEM I), the cement content of 350 kg/m^3 was constant for all the mixers in this study. The glass used in this study is waste glass after it has been broken and ground to certain degrees. Waste glass powder (GP) as in Figure (3-a) was used as an addition to the cement weight by 10%, 20%, 30% and passed through a 0.075 mm sieve. The recycled glass waste was used as a fine aggregate (GF) as a substitute for sand as in Figure (3-b) and passed through a 1.18 mm sieve with a replacement ratio of 10%, 20%, 30%. Glass waste powder was used as an addition to the weight of the cement and used fine Glass waste as a substitute for sand in one mixture at a rate of 20%. Table (3) shows the chemical composition of glass waste powder and Figure (4) shows the grading curve for fine glass waste (GF) used as a sand substitute. due to more sharper and irregular geometric forms of the glass particles compared to sand particles, which may give rise to high friction and such resulted in less fluidity, thus, chemical and mineral additives were used to improve the performance and strength. Two types of additives were used for the mixtures of recycled glass waste, namely: The first type: liquid super plasticizer (sikament-163M) It is considered a highly efficient additive to reduce the mixing water content to a high degree and as a strong plasticizing agent that increases the workability, and it was used at a rate of 0.6% of the weight of the cement materials for all mixtures These plasticizers are compatible with all types of Portland cement and their natural properties are (brown liquid - density 1.20 ± 0.005 kg / liter - the dose ranges from 0.6-2.5% by weight of cement). The second type: fine powder additive (Sikacret HD) (SC), this type of additive gives concrete several characteristics, including high performance and high durability. These additives are gray in color and have a specific density of 0.5. They were used at a rate of 5% of the cement weight.

Table 1: Physical and Mechanical Properties of Dolomite Aggregates

Property	Results	BS-En-1197-2009
Absorption,%	2.6 %	Not more than 3%
Impact coefficient	22.72 %	Not more than 45%
Crushing coefficient	24.43 %	Not more than 45%
Specific gravity	2.64	2.6-2.7
Weight unite volume	1478	1400-1800 Kg/m^3

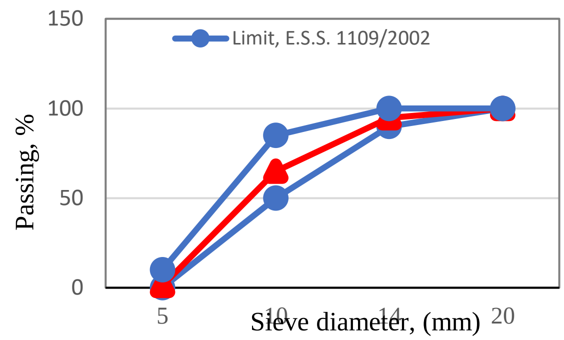


Fig.1: Sieve analysis results for dolomite aggregate

Table 2: Physical Properties of Fine Aggregate.

Property	Results	BS-En-1197-2009
Absorption,%	0.28 %	Not more than 3%
Specific gravity	2.57	2.5 – 2.7
Weight unite volume	1690.86	1400-1800 Kg/m^3

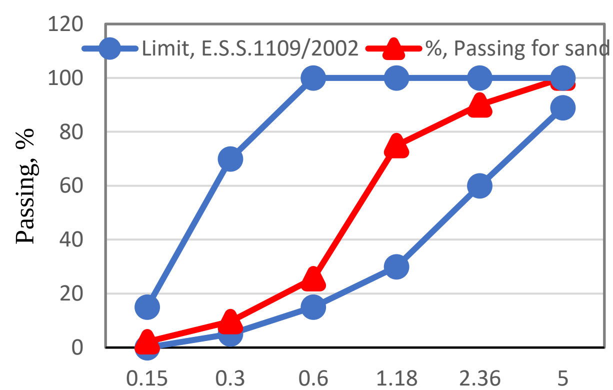


Fig.2 : Sieve analysis results for sand.

Table 3: Chemical composition of glass waste powder.

Chemical Composition	**%**
SiO_2	65.77

(a)

(b)

Fe_2O_3	2.13
Al_2O_3	1.73
CaO	22.24
MgO	0.82
SO_3	0.04
Na_2O	5.23
K_2O	0.48
Cl	0.13

(b)

Fig. 3. Waste glass particles: (a) Glass powder (GP), Glass fine aggregate (GF).

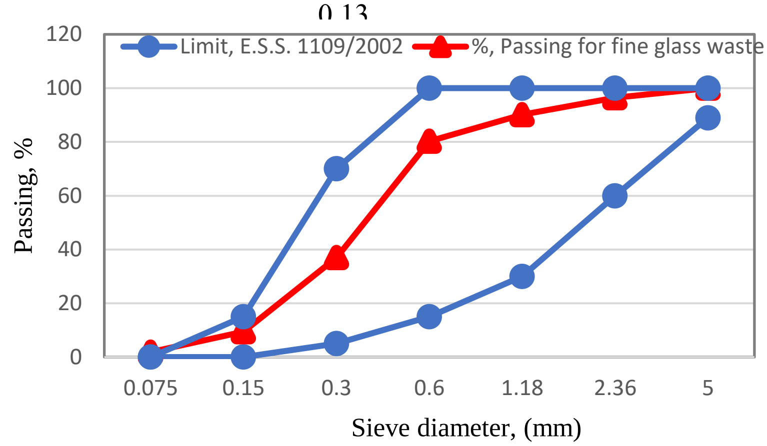


Fig. 4: Sieve analysis results for glass fine aggregate (GF)

4 .2 Mix Design:

The absolute volume equation was used in this study to find the quantities required by weight for each of cement, aggregate and water for a cubic meter of fresh fully compacted concrete, where a constant ratio of 1:2 was used for fine aggregate: coarse aggregate, and the ratio of water/cement materials (w/cm) was fixed 0.5 and the cement content is 350 kg/m^3 for all concrete mixtures in this study. Chemical additives (super plasticizer) sikament163M were used at a rate of 0.6% of the weight of the cement materials, and pozzolanic materials in the form of fine powder Sikacret HD (SC) at a rate of 5% were used for all concrete mixtures. Table (4) shows the percentage and quantities of concrete mixes in this study for one cubic meter of fresh concrete.

Table 4: percentages and quantities of used concrete mix components

Glass waste	**Glass waste**				Cement content (Kg/m^3)	Aggregates		Chemical additives		Pozzolanic materials		water/cement materials (W/cm*)	
	Fine agg.)GF(		Powder)GP(										
	%	Weight (Kg)	%	Weight (Kg)		Sand (Kg/m^3)	Dolomite (Kg/m^3)	%	Weight (Kg)	%	Weight (Kg)	%	Weight (Lit)
M_R	0	0	0	0		627	1254		0		0		175
M_{GP10}	-	-	10	35		577	1154		2.42		17.5		201.3
M_{GP20}	-	-	20	70		563.4	1126.8		2.63		17.5		218.75
M_{GP30}	-	-	30	105	350	549.82	1099.64	0.6	2.84	5	17.5	0.5	245
M_{GF10}	10	58.7	-	-		528.6	1172.8		2.20		17.5		183.7
M_{GF20}	20	116.8	-	-		467.1	1167.7		2.20		17.5		183.7
M_{GF30}	30	174.4	-	-		406.9	1162.6		2.20		17.5		183.7
$M_{(GF+FP)20}$	20	111.1	20	70		444.5	1111.22		2.63		17.5		218.7

Cement materials (cm*): It consists of cement, Pozzolanic materials and glass waste powder

4.3 The Specimens and the Tests Used in This Study

With respect to the Specimens, it is a metal cube models with dimensions of 10 cm x 10 cm x 10 cm for compressive strength, porosity, absorption tests. And metal cylinders models with dimensions of 15 cm in diameter and 30 cm in height for an indirect tensile test as shown in Figure (5). With respect to the tests, the slump test was carried out to determine the workability of fresh concrete after the mixing process and before pouring the samples. The indirect tensile and compressive strength tests were carried out and the density was determined for the hardened concrete after pouring the samples and removing them from the models after 24 hours and placed in a treatment basin at room temperature until tested after 28, 56 days of casting. The porosity test was carried out for the concrete samples in this study in order to determine the percentage of voids inside the samples by placing them in water until saturation for a period of 3 days and then weighting them while they were saturated in air (Wsat.). After that, the saturated sample is weighted while it is immersed in water (Wwat.). After that, the same sample is placed in an oven with a temperature of 100-110 ^{0}C for a period of 24 hours, and then it is weighted while it is dry, as shown in Figure 6. The percentage of porosity (S%) was calculated. The absorption test was carried out for concrete samples in this study, which is the ability of concrete to draw water into its gaps, which leads to swelling and crumbling of the concrete when exposed to freezing and thawing cycles while it is saturated with water and then a weighting let it be $W_{2.}$. After that, the sample was placed in an electric oven, with a temperature ranging from 100-110 °C for 24 hours, in order to dry it completely and weight it, let it be W_1,the percentage of absorption was calculated. The density of the concrete was determined by finding the weight of the sample (W) after curing it for 28 days and drying its surface. The volume of the sample (V) was calculated, and then the density (ρ) was calculated. Table 5 shows the general layout for samples and tests used in this study.

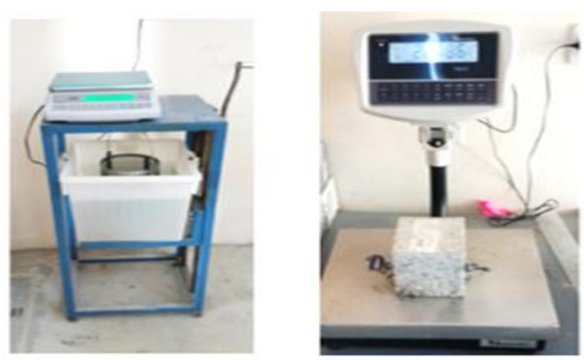
$$S(\%) = \frac{Wsat - Wdry}{Wsat - Wwat}\ x\ 100$$

$$Absorption, \% = \frac{W2 - W1}{W1} x\ 100$$

$$\rho = \frac{W}{V}$$

(a) (b)

Fig. 5: The specimens for compressive and splitting tensile strength test:
(a) Metal cylinders with dimensions15 cm x 30 cm
(b) Metal cubes with dimensions (10 x 10 x 10) cm



(a) (b)

Fig. 6: Weight the specimens :
(a) In the case of specimens saturated with water
(b) In the case of air-dried specimens

5. Results and Discusion

5.1 Effect of glass waste on workability for concrete mixtures

The workability of fresh concrete has been studied by conducting a slump test, where the slump amount was determined for all the mixtures immediately after the mixing process, as in figure (7), and the results showed that the slump amount increased with the addition of the glass powder percentage (GP) compared to its value for the reference mixture (M_R). It was also found that the workability of concrete containing glass fines (GF) improves by increasing the percentage of replacement of fine aggregates with glass fines, compared to the workability of the reference mixture. Also, it was shown that the concrete containing powder and glass fines together gives the best workability compared to the rest of the mixtures M_R, M_{GP}, and M_{GF}. The explanation for the increase in workability in the study is as a result of the use of liquid plasticizers and fine powder additive (Sikacret HD), as previous research has proven that the use of only powdered glass waste reduces workability as a result of the increase in its surface area as well as the angular shape of the glass particles.

Table 5: General layout for Specimens used in this study

Mix type	Cement content, (Kg/m³)	Glass waste		Specimens No.	
		Fine agg.)GF(	Powder)GP(	Cubes 10×10×10 cm	Cylinder 15×30 cm
M_R	350	-	-	9	6
M_{GP10}		-	10 %	9	6
M_{GP20}		-	20 %	9	6
M_G					6
M_{GF10}		10 %	-	9	6
M_{GF20}		20 %	-	9	6
M_{GF30}		30 %	-	9	6
$M_{(GF+FP)20}$		20 %	20 %	9	6

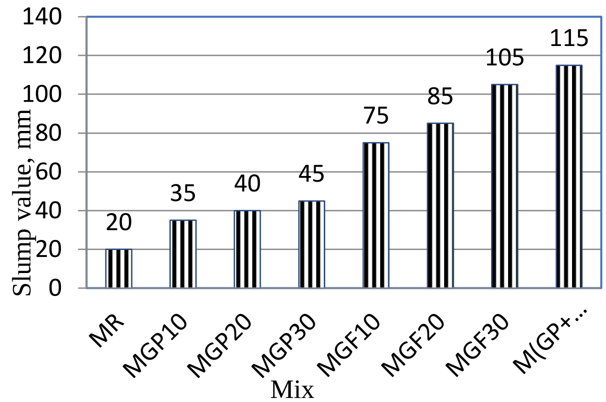


Fig. 7: Workability for reference mix and glass concrete waste mixtures-

5.2 Compressive Strength Test

5.2.1 Effect of powder and fine aggregate for glass waste on compressive strength for concrete mixtures at ages 28 and 56 day.

The compressive strength test was conducted on the concrete cube samples after they were treated with water for a period of 28, 56 days from the date of casting, and the results were recorded in Table (6).The effect of adding waste glass powder (GP) as a percentage of cement weight on the compressive strength of concrete at the age of 28, 56 days was studied. The results showed that at a curing age of 28 days, as shown in figure (8), there was a decrease in the compressive strength value with an increase in the addition percentage (GP) from 10% to 30% compared to the reference mixture. Also, at the same age of concrete, the effect of fine glass waste (GF) was studied as a replacement for fine aggregate (sand) on the compressive strength of concrete, as in figure (9), an increase in compressive strength was shown by 5.24% when using GF by 10%, and then it decreases at 20%. 30% compared to the reference mixture by 5% and 40%, respectively. The effect of using powder and glass fines together by 20% on the compressive strength of concrete was studied, as in figure (10) and it was found that there was a decrease in the strength of up to 21.7% compared to its value for the reference mixture. The results showed that at a curing age of 56 days, as shown in figure (11), an increase in the compressive strength reached 3%, 6.5% at the percentage of addition (GP) 10%, 20%, respectively, and then a decrease occurred in comparison to the reference mixture. Also, at the same age of concrete, the effect of fine glass waste (GF) was studied as a replacement for fine aggregate (sand) on the compressive strength of concrete, as in figure (12) an increase in compressive strength was shown by 24.7% and 11.6 % at 10 % and 20 % GF replacement for sand respectively, and then a decrease occurred compared to the reference mixture. The effect of using powder and glass fines together by 20% on the compressive strength of concrete was studied, as in figure (13) and it was found that there was a decrease in the strength of up to 11.2% compared to its value for the reference mixture.

These outcomes are in agreement with the past studies reported in the literature wherein the optimum replacement content was 30% owing to the shortage of Calcium Hydroxide which is essential for the pozzolanic reaction for producing secondary Calcium Silicate Hydrate (Du, H. and K. H. Tan., 2017). From microstructure, the result of Scanning Electron Microscopy (SEM) analysis for the concrete without waste glass shows a boundary between the cement and aggregates but the boundary become more invisible after 18% waste glass replacement. This is due to the waste glass that was dispersed uniformly in the concrete structure thus creating denser concrete and helps to improve the compressive strength and split tensile strength of the waste glass concrete. However, voids started to appear in the images of 18% waste glass replacement and 20% waste glass replacement. The number of voids increased as the waste glass replacement increased and cracks can be seen when the replacement percentage is higher than 20%. The existence of the cracks will be one of the reasons for the decrease of compressive strength and split tensile strength (Samuel J and Raju K L, 2018).

Table 6: Compressive strength test results.

Mix type	**Glass waste**		**Compressive strength, Mpa**	
	Fine agg. (GF)	**Powder (GP)**	**at 28 days**	**at 56 day**
M_R	-	-	43.9	42.9
M_{GP10}	-	10 %	34.4	44.2
M_{GP20}	-	20 %	32.2	45.7
M_{GP30}	-	30 %	22.7	31.2
M_{GF10}	10 %	-	46.2	53.5
M_{GF20}	20 %	-	41.7	47.9
M_{GF30}	30 %	-	26.2	28.7
$M_{(GF+FP)20}$	20 %	20 %	34.4	38.1

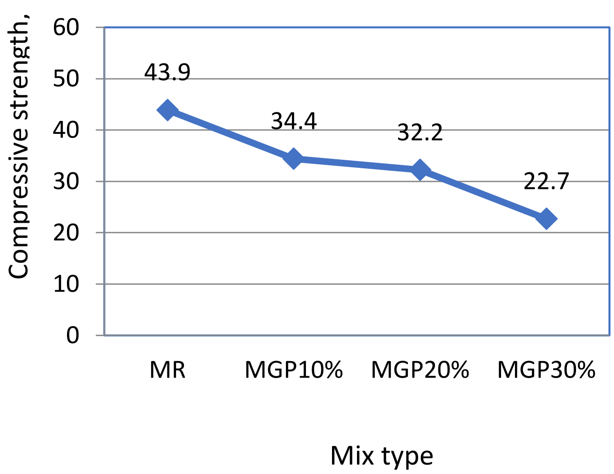


Figure 8. Effect of adding GP on the compressive strength of concrete at 28 days.

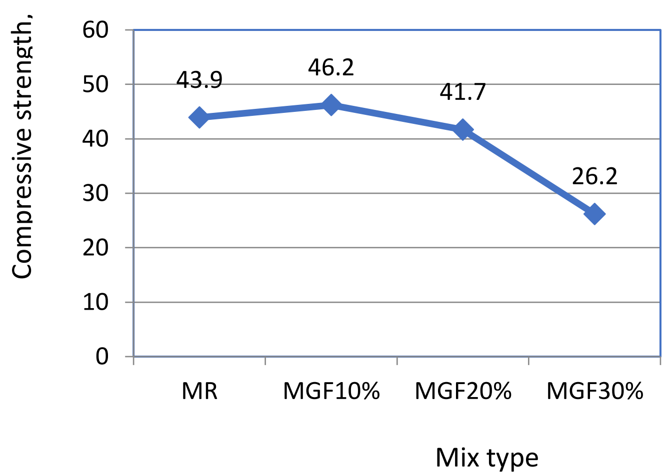


Figure 9. Effect of replacing part of the sand with GF on compressive resistance at 28 days

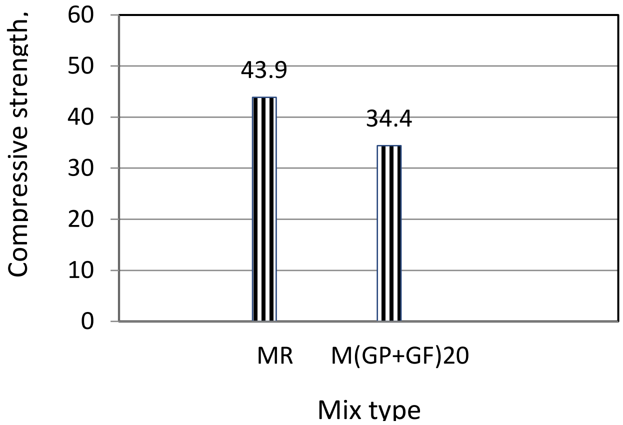


Figure 10. Effect of both Gp and GF together by 20% on the compressive strength of concrete at a curing age of 28 days

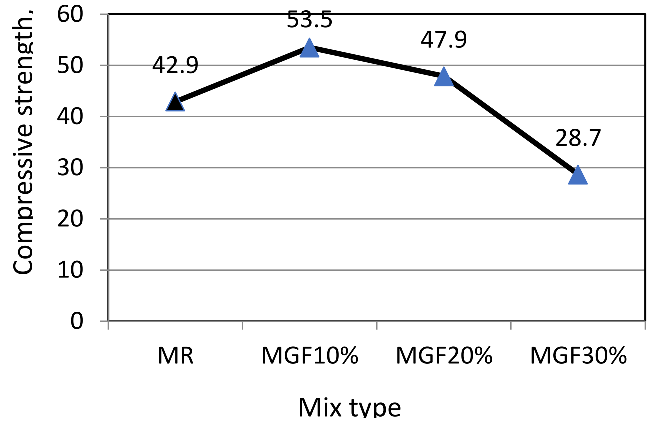


Figure 12: Effect of replacing part of the sand with GF on compressive resistance at 56 days

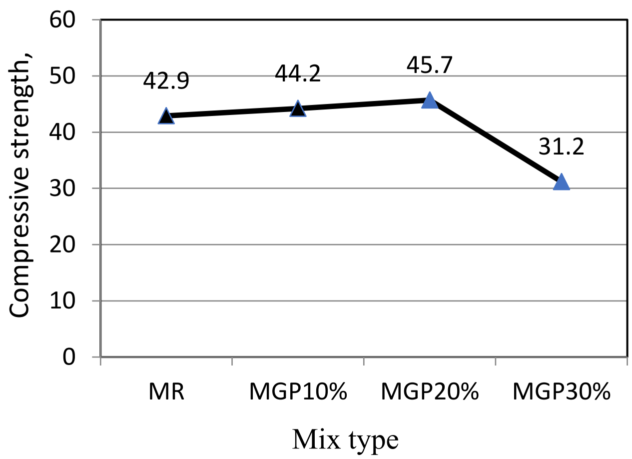


Figure 11. Effect of adding GP on the compressive strength of concrete at 56 days.

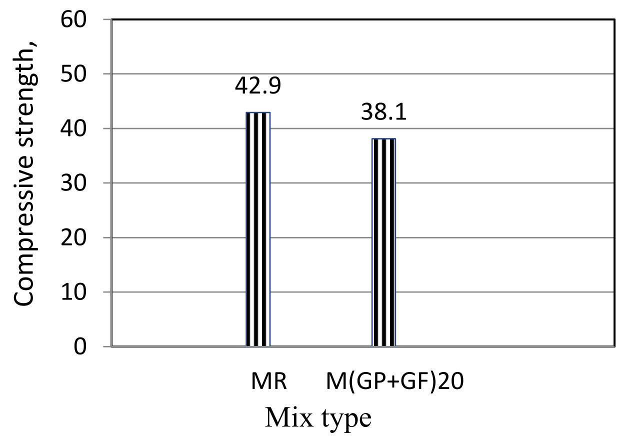
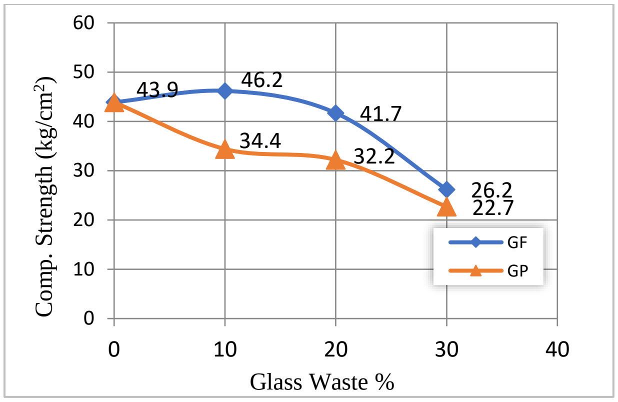


Figure (13): Effect of GP and GF together by 20% on the compressive strength of concrete at 56 days

Comparing the glass waste concrete with the reference concrete as in figure (14) at a curing age of 28 days, the results show fine aggregate glass waste concrete (GF), which gives higher compressive strength compared to glass waste powder concrete (GP) at all ratios (10, 20, 30) %. The compressive strength of both decreases, but the compressive strength value of concrete containing fine glass waste improves only at 10% compared to the reference mixture.

Comparing the glass waste concrete with the reference concrete as in from figure (15) at a curing age of 56 days, the results shows an improvement in the compressive strength of the concrete of both fine aggregate and glass waste powder at the percentages (10,20)%, and then decreases at 30% compared to the strength of the reference mixture. Also, the compressive strength of fine aggregate glass waste concrete is better compared to glass waste powder concrete at percentages (10, 20) %, while it is less at 30%.



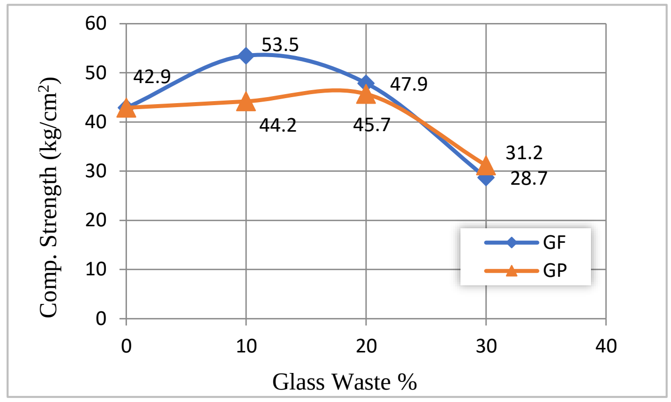


Figure. 14: Effect of the percentage of glass waste on the compressive strength at 28 days.

Figure. 15: Effect of the percentage of glass waste on the compressive strength at 56 days.

5.2.2 Effect of concrete age on the compressive strength of concrete containing powder and fine glass waste

As shown in figure (16), At 56 days, there was no improvement in the compressive strength of the reference concrete, but there was a clear improvement in the compressive strength of glass powder concrete by 28.5 %, 41.9 %, and 35.6 % at the ratios (10,20,30) %, respectively compared to its strength at 28 days. Figure (18) shows that at the age of 56 days, there is no improvement in the reference compressive strength, while it is noted that there is a clear improvement in the compressive strength by 15.8%, 14.8%, and 9.5% at the percentages (10,20,30)%, respectively, compared to the strength at the age of 28 days. This may be attributed to the Pozzolanic reaction that appears to offset this trend at a later stage of hardening and such contributes to an improvement in the compressive strength at 56 days. A similar observation was reported by (Metwally, I.M., 2007) **.**

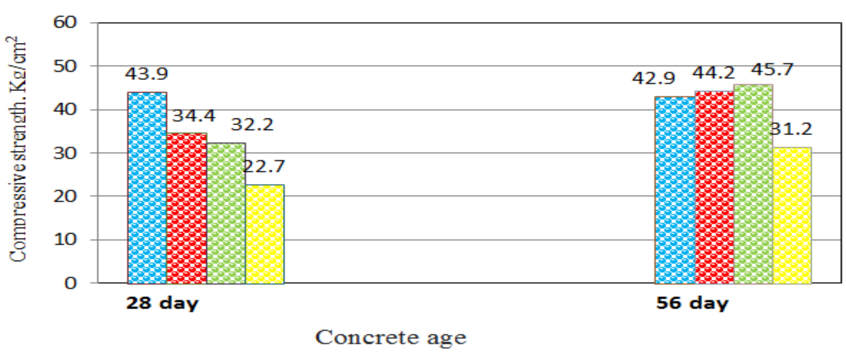


Figure 16: Effect of the age on the compressive strength for the concrete containing glass powder

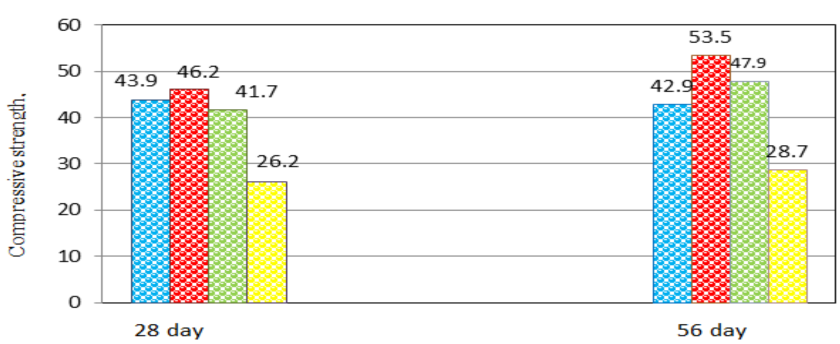


Figure 17: Effect of the age on the compressive strength for the concrete containing glass fine aggregate.

5.3 Indirect Tensile Strength Test (Splitting Tensile Strength)

Indirect tensile strength test was carried out on cylindrical samples after curing them with water for a period of 28, 56 days from the date of casting, and the results were shown in table (8). Effect of adding glass waste powder (GP) as a percentage of the weight of cement on the indirect tensile strength was studied as in figures (18), (19) and it were found that similar to the compressive strength, there was a decrease in the value of the indirect tensile strength with the increase in the percentage of (GP) addition from 10% to 30% compared to the reference mixture. There is a slight improvement in the reference indirect tensile strength, while it is noted that there is a clear improvement in indirect tensile strength at the percentages (10,20,30)%, respectively, compared to the strength at the age of 28 days. Also, a decrease in the tensile strength value occurred with an increase in the percentage of using fine glass waste (GF) as a replacement for fine aggregate (sand) from 10% to 30% compared to the reference mixture, as in figures (20), (21). Effect of using powder and glass fines together by 20% on the indirect tensile strength of concrete was studied, and it was found that there was a decrease in the strength of up to 36.7%, 30.4%, compared to the value of the reference mixture at a curing age of 28, 56 days, respectively, as in figures (22), (23).

Table 7: Indirect Tensile Strength Test results

Mix type	**Glass waste**		**Indirect Tensile strength, Mpa**	
	Fine agg (GF)	**Powder (GP)**	**at 28 days**	**at 56 days**
M_R	-	-	3.49	3.98
M_{GP10}	-	10 %	2.25	3.08
M_{GP20}	-	20 %	2.59	3.05
M_{GP30}	-	30 %	2.24	2.47
M_{GF10}	10 %	-	3.12	2.91
M_{GF20}	20 %	-	3	2.81
M_{GF30}	30 %	-	2.22	2.48
$M_{(GF+FP)20}$	20 %	20 %	2.2	2.77

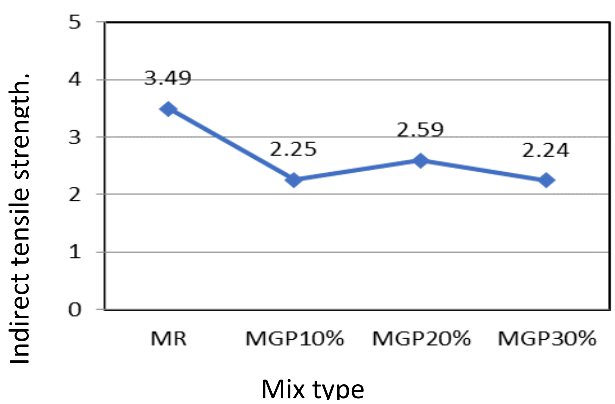


Figure 18. Effect of adding GP on Indirect tensile strength of concrete at 28 days.

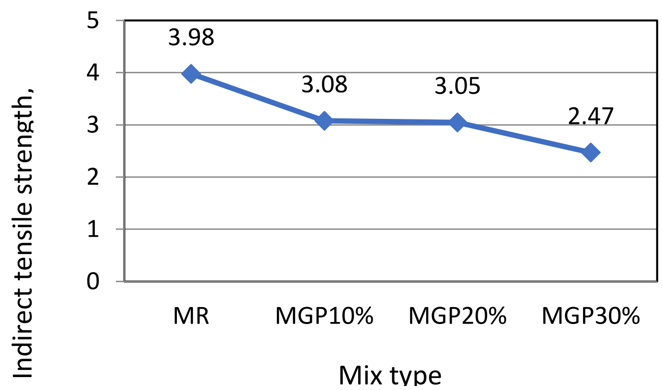


Figure 19. Effect of adding GP on Indirect tensile strength of concrete at 56 days.

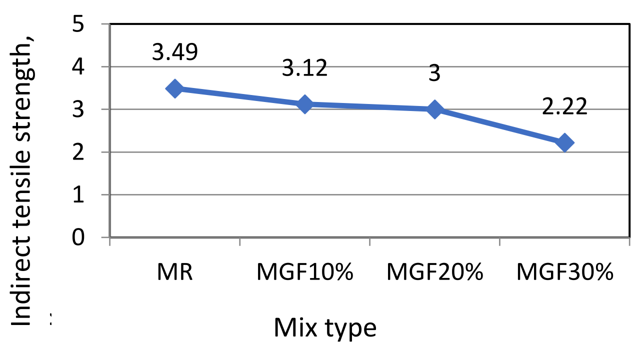


Figure 20. Effect of replacing part of the sand with GF on Indirect tensile strength at 28 days

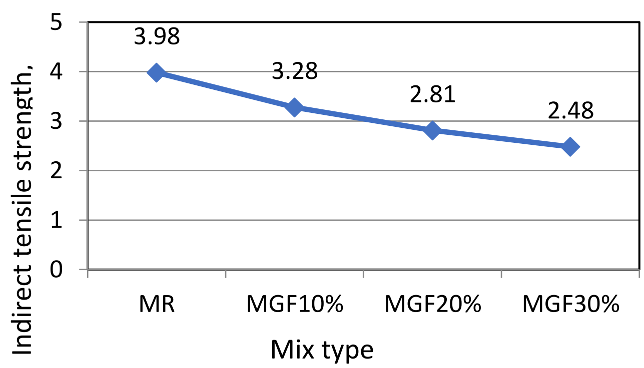


Figure 21. Effect of replacing part of the sand with GF on Indirect tensile strength at 56 days

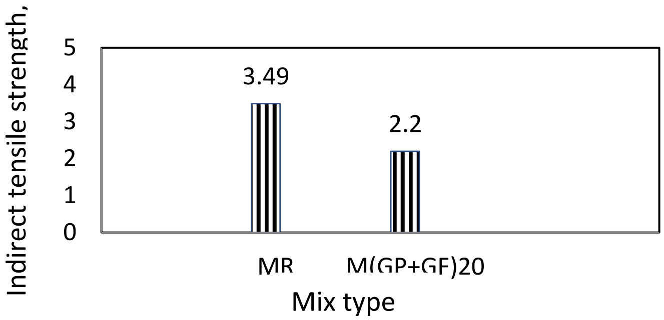


Figure 22. Effect of Gp and GF together by 20% on indirect tensile strength of concrete at 28 days

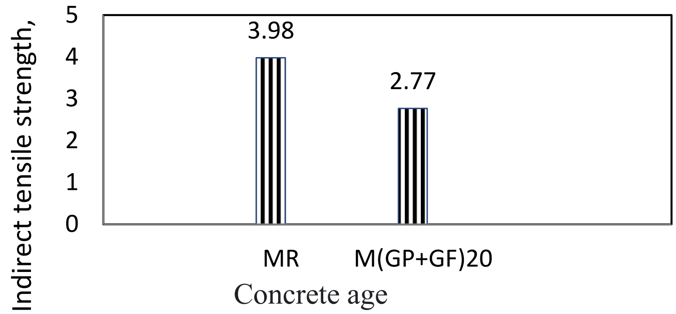


Figure 23. Effect of Gp and GF together by 20% on indirect tensile strength of concrete at 56 days

Comparing the glass waste concrete with the reference concrete as in figure (24) at a curing age of 28 days, the results showed that the indirect tensile strength of glass waste fine concrete (GF) is higher compared to its value for glass waste powder concrete (GP) at (10,20)%, while the tensile strength of both is similar at 30%.It is also noted that the tensile strength of glass waste concrete (fine aggregate and powder) is less compared to the strength of the reference mixture.

Comparing the glass waste concrete with the reference concrete as in From figure (25) at a curing age of 56 days, the results showed that the indirect tensile strength of glass waste fine concrete (GF) is higher by a simple value compared to its value for glass waste powder concrete (GP) at all ratios (10, 20, 30) %. It is also noted that the tensile strength of glass waste concrete (fine aggregate and powder) is less compared to the resistance of the reference mixture.

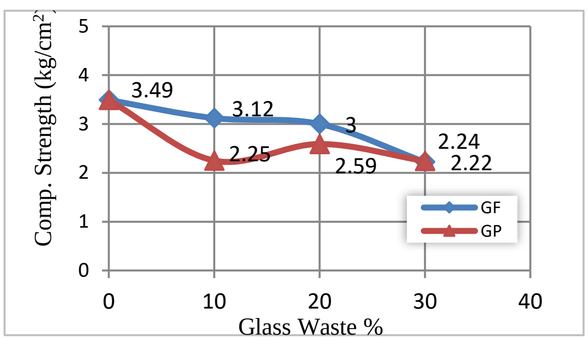


Figure. 24: Effect of percentage of glass waste on the indirect tensile strength at 28 days

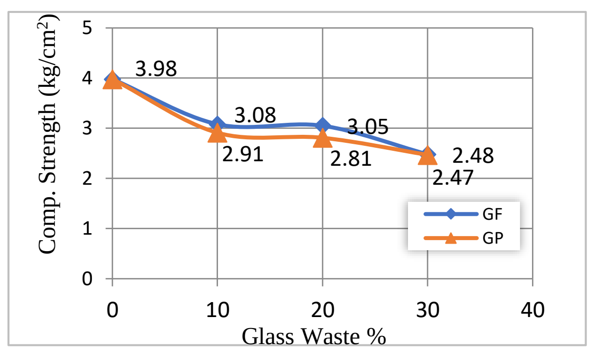


Figure.25: Effect of the percentage of glass waste on the indirect tensile strength at 56 days

5.4 Effect of Glass Waste on the Porosity

The porosity of reference concrete and concrete containing powder and fine glass waste was studied, and the results were shown in table (8). Figure 26 shows the porosity of glass waste powder concrete is higher at the replacement rate of 30 % compared to the rest of the study mixtures, and also the porosity of fine glass waste concrete is higher compared to the porosity of glass waste powder concrete at the ratios of 10, 20 % and reference concrete. The porosity of concrete containing powder and fine glass waste together by 20% increased up to 99% compared to reference concrete.

Table 8. Porosity of concrete mixtures results

Mix type	Porosity, (S %)	Mix type	Porosity, (S) %
M_R	7.26	M_{GF10}	13.19
M_{GP10}	9.09	M_{GF20}	13.32
M_{GP20}	12.08	M_{GF30}	14.96
M_{GP30}	16.02	$M_{(GF+FP)20}$	14.44

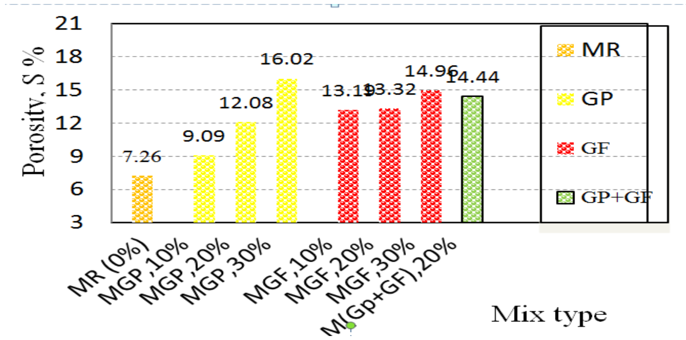


Fig. 26: Effect of glass waste percentages on concrete porosity

5.5 Effect of Glass Waste on the Water Absorption of Concrete

The absorption of reference concrete and concrete containing powder and fine glass waste was studied, and the results were shown in table (9). Figure (27) shows that the absorption of glass waste powder concrete is higher at the replacement rate of 30% compared to the rest of the study mixtures, and also the absorption of fine glass waste concrete is higher compared to the absorption of glass waste powder concrete at the ratios of 10, 20% and reference concrete. And the absorption of concrete containing powder and fine glass waste together by 20%, reaching 112.7%, compared to the reference concrete.

Table 9: Absorption of concrete mixtures results

Mix type	Absorption, %	Mix type	Absorption, %
M_R	3.07	M_{GF10}	5.75
M_{GP10}	4.28	M_{GF20}	5.96
M_{GP20}	5.85	M_{GF30}	6.69
M_{GP30}	8.18	$M_{(GF+FP)20}$	6.53

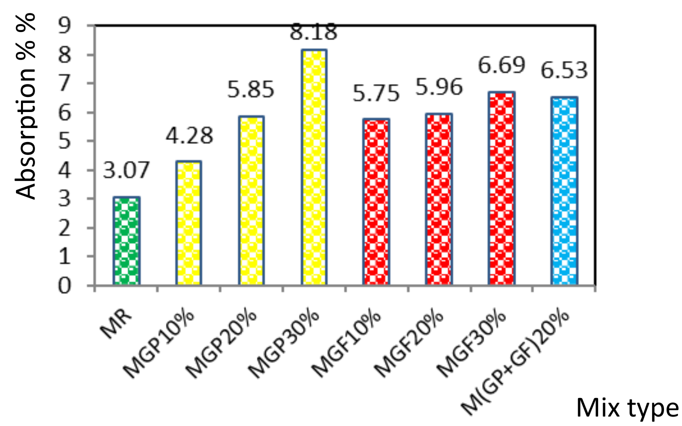


Figure 27: Effect of glass waste percentages on concrete absorption

5.6 Effect of Glass Waste on the Concrete Density

The density of reference concrete and concrete containing powder and fine glass waste was studied, and the results were shown in table (10). figure (28) shows that the density of concrete decreases with an increase in the percentage of powder and glass fines compared to the density of reference concrete. and the density of fine glass waste concrete was also higher compared to the density of powder glass waste concrete at all ratios (10,20,30)%. The density of concrete containing powder and fine glass waste together decreases by up to 5% compared to its value for reference concrete. From the importance of decreasing the density of glass waste concrete, we can use it effectively when light concrete is needed

Table 10: Density of concrete mixtures results

Mix type	Density, Kg/m³	Mix type	Density, Kg/m³
M_R	2454.3	M_{GF10}	2418.1
M_{GP10}	2350.8	M_{GF20}	2388.8
M_{GP20}	2310.3	M_{GF30}	2335.5
M_{GP30}	2269	$M_{(GF+FP)20}$	2333.3

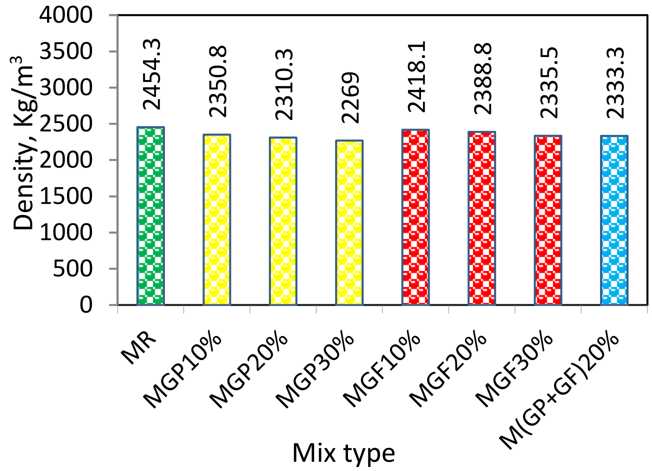


Figure 28.: Effect of glass waste percentages on concrete density

6. Conclusions

This study reported experimental study for some properties of concrete containing glass waste. Based on the newly obtained results, the following conclusions can be drawn:

- The results of the research showed that, the use of both fine glass waste as a replacement for sand in different proportions and glass waste powder as additional proportions of cement gives higher workability by an average rate of up to 120% and 100% compared to the control mixture, respectively.
- Comparing the effect of using fine glass waste and glass waste powder on the workability of concrete, it was found that fine glass waste gives higher workability by an average of 120%.
- For glass waste fine aggregate (GF), it was found in this study at the age of 28 days, that there was an improvement in compressive strength up to 5% for concrete mixtures containing glass fines 10% replacement for sand, after which the strength decreased compared to the control mixture. While at the age of 56 day, that there was an increasing in the compressive strength up to 24.7 % and 11.6 % at 10 % and 20 % GF replacement for sand respectively, and then a decrease occurred compared to the control mixture.
- For glass waste powder (GP), It was found in this study at the age of 28 days, had less compressive strength compared to the control mixture at all percentages. While at the age of 56 day, that the was an increase in the compressive strength reached 3%, 6.5% at the percentage of addition (GP) 10%, 20%, respectively, and then a decrease occurred in comparison to the control mixture.
- The effect of using powder and glass fines together by 20% on the compressive and indirect tensile strength of concrete was studied, and it was found that there was a decrease in the strength at the age of 28 and 56 day compared to the control mixture, but the decrease in strength is small at the age of 56 compared to the age of 28 days.
- The indirect tensile strength of glass waste powder concrete decreases significantly at the concrete curing ages of 28 and 56 days, reaching 113% and 111%, respectively, compared to control concrete. Also, the tensile strength of fine glass waste aggregate concrete decreases at the same concrete curing ages by rates of up to 71% and 98% compared to control concrete.
- The percentage of water absorption and porosity of the glass concrete is higher compared to the control mixture.
- By determining the density, it was found that the density of the glass concrete is lower compared to the density of the control concrete. From the importance of decreasing the density of glass waste concrete, we can use it effectively when light concrete is needed

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