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PROPERTIES OF HIGH STRENGTH ECO-FRIENDLY CONCRETE WITH GLASS WASTE POWDER

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ABSTRACT

This investigation includes the use of glass wastes after recycling to produce High Strength Eco- Friendly Concrete. The glass waste was collected, crushed, and grinded for 10 minutes to produce a powder with fineness higher than that for cement of about 7340 cm2/gm. Many tests were conducted on this powder including, chemical analysis, pozzolanic activity index tests, and the remaining content on sieve of 45 microns. The results show that the glass waste powder considered as a natural Pozzolan class (N) according to ASTMC618.

Many concrete mixes with different percentages of glass waste powder as a partial replacement to cement (10%, 15%, 20%, 25%, and 30%) were prepared. The properties of concrete (fresh density, compressive strength at 7, 28, 60, and 90 days age, and water absorption at 60 days age)were studied and compared with the results of the reference concrete mix (without glass powder). The compressive strength for concrete specimens with 10%, 15% glass powder content at 28, and 60 days age is increased. When the content of glass powder is increased to 20%, 25%, and 30%, the compressive strength is decreased compared with the reference concrete specimens. The highest percentages increase in compressive strength are 1.17%, 13.3%, 19.34% for specimens with 15% glass powder at 28, 60 and 90 days age respectively, while the water absorption is decreased.

Keywords: *High strength concrete, Sustainable concrete, Glass waste powder, Green concrete, Eco- friendly concrete.*

I. INTRODUCTION

Huge quantities of waste glass began generating all around the world due to the large use of these products. Most of these solids wastes have been buried in landfill sites; this land filling of wastes are unfavorable because these wastes are non-biodegradable, which make this process environmentally less friendly. It is required to start a new solution for sustainable development. One of the best solutions of sustainable solid waste management is the ability to Reduce, Reuse and Recycling of this waste to the maximum as possible [1, 2].

The production of one ton of cement leads to about one ton of CO_2; this makes concrete less friendly to environment. Therefore it's necessary to reduce as much as possible the amount of cement in concrete industry. The use of many types of supplementary cementitious materials especially the by-product materials (fly ash, silica fume, ground-granulated blast-furnace slag, etc.) as a replacement to cement shows a significant interest by many researchers [3, 4, 5]. This is because the inclusion of these materials leads to produce an environmental friendly concrete.

The chemical composition of these materials mainly contains reactive silica that reacts with $Ca(OH)_2$(one of the hydration products of cement) to produce additional gel, which improves some properties of concrete [6, 7, 8]. In addition to by-products supplementary cementitious materials from industry, there are natural materials, named natural Pozzolans, such as Metakaolin that produced from burning the kaolin clay to a temperature between 600-800 C^o[9, 10].

In Iraq the by–product supplementary cementitious materials such as, silica fume, fly ash, etc. are not available, while kaolin clay is exist in large deposits in Iraq. However, the use of Metakaolin as a replacement to cement consumes the kaolin clay from environment, in addition it consumes large amount of energy during the burning process that make this material less sustainable. Therefore, it is very important to find alternative sustainable material that can be used as a replacement to cement in concrete industry.

Glass is a diaphanous material produced from melting a mix of soda, silica, and calcium carbonate at high temperatures and then cooling this mix. Recently the quantity of glass waste is increased in Iraq due to the use of glass in different industries (bottles, windows, etc.). Therefore, it is necessary to utilize glass waste material and reuse it in concrete. The use of these wastes also reduces the construction cost [11].

Many efforts were carried out by many researchers to use glass waste in concrete as aggregate. The results show that glass waste aggregate causes durability problem in concrete because it causes alkali-silica reaction that leads to deterioration of concrete [12, 13, 14]. The chemical composition of the glass waste consists of high content of active silica, so this waste can be crushed and grinded to very fine particles and used as a partial replacement to the cement in concrete.

II. MATERIALS & METHODS

Materials

Ordinary Portland cement type (I) was used in this investigation. The test results show that the cement used is compatible with Iraqi standards No.5/1984[15]. Natural sand (with maximum aggregate size of 4.75mm was used. The sieve analysis and physical properties demonstrate that the fine aggregate used is within the requirements of the Iraqi Standard No.45/1980[16].Natural crushed coarse aggregate with nominal maximum size of 14 mm was used in this study. The grading and sulphate content of the coarse aggregate satisfy the requirements of Iraqi Standard No. 45/ 1980[16].The water used for mixing and curing of concrete was potable water from the water supply network (tap water).Also high range water-reducing admixture (superplasticizer) with a commercial mark of GLENIUM 54® was used. The recommended dosage by the manufacturer was in the range of 0.5-2.5 liters/100 kg of the cement. This type of admixture is free from chlorides and compatible with ASTM C494-04 type F [17].White glass were collected, washed and broken into small pieces as shown in Figure (1a).The glass was then crushed to small particles of about 0.5 mm as shown in Figure (1c) by using a crusher type (Retsch) shown in Figure (1b). Then it was grinded by a grinder type (Retsch) as shown in Figure (1d). The grinding was carried out for different time periods (1, 5, 10, and 15 minutes). Glass powder sample after grinding process is shown in Figure (1e).The glass powder then screened on sieve No. 200 (75 microns) as shown in Figure (1f).

Experimental Test on glass powder

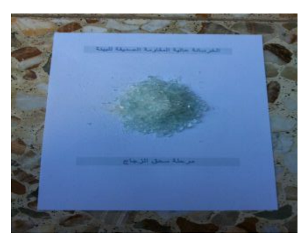
The following tests had been conducted on the prepared glass powder to make sure that this powder has properties confirms to the properties of natural pozzolans:

Fineness Test

The test was carried out on the glass powder after each grinding period (1, 5, 10, and 15 minutes) in accordance to ASTM C-204 (Blain method)[18].The results in Table (1) show that 10 minutes grinding period gives the highest fineness for glass waste powder.

a- Collecting Glass Process.

b- Crusher Type Retsch.



c- Glass Waste After Crushing.

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d- Grinder Type Retsch.

e- Glass Waste Sample After Grinding Process.

f- Waste Sample After Screen Process.

Figure (1) Preparation of Glass Waste Powder.

Table (1) Fineness of Glass Waste powder.

Time of grinding (Minutes)	Fineness (Blain Method) (cm^2/gm)
1	3100
5	6161
10	7340
15	7057

Strength Activity Index (S.A.I.)

Strength activity index of glass waste powder at 7and 28 days age were conducted according to ASTM C311 and compared with limits of ASTM C-618[19]. The result is shown in Table (2).

The Remaining Content on the Sieve of 45 Microns (No. 325).

The test was conducted on glass powder according to ASTM C-430 [20]. The result is shown in Table (2).

The Chemical Analysis (Quantitative and Qualitative)

Chemical analysis was carried out for glass waste powder using X-ray diffraction by EDX-7000 device [21]. The X-ray diffraction of the glass waste powder is shown in Figure (2). The properties of glass waste powder are shown in Table (2).

Concrete Mixing procedure

The mixing process was performed in an electrical rotary vessel mixer of 0.1m3 capacity. For concrete mixes containing glass waste powder the coarse and fine aggregate were in saturated and surface dry (SSD) conditions and mixed for one minute. Cement and glass waste powder were mixed by hand for five minutes , and then 60% of the mixing water was added to the dry mixture and mixed for one minute. The superplasticizer was mixed with the 40% remaining mixing water, then it is added to the mix and mixed for two minutes.

Preparation of Concrete Specimens

The steel molds were cleaned their internal surfaces were lubricated to prevent adhesion with concrete after hardening. The molds were filled compacted by a vibrating table according to ASTM C- 192/C192M [22], which is a sufficient period to remove any entrapped air. After compaction, the specimens were leveled by hand troweling, and covered with polyethylene and left for 24 hours, then removed from molds, and cured concrete till the time of specimens test. After removing the concrete specimens from molds, all the specimens were completely submerged in water containing 3gm/liter of calcium hydroxide in water storage tank according to ASTM C511[23]. Concrete specimens were cured till the time of test.

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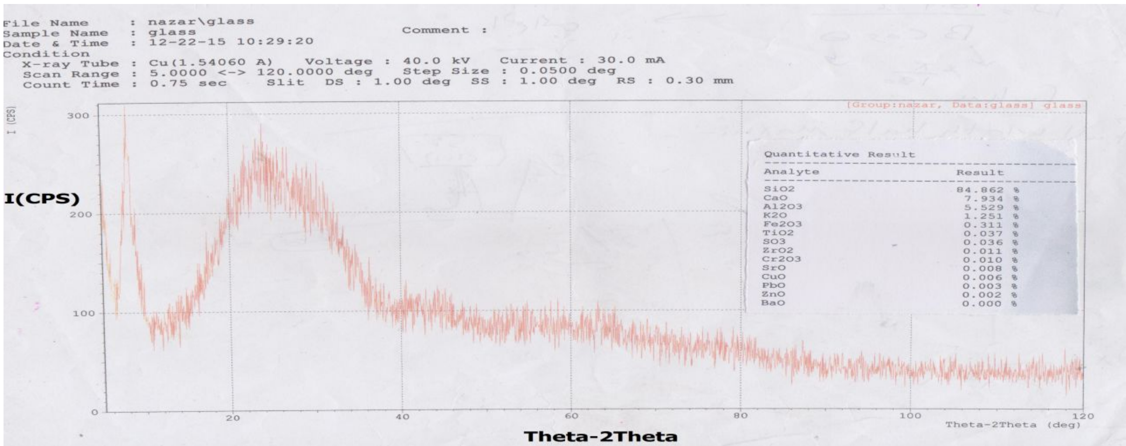

Figure (2) X- ray Spectrum for Glass Waste Powder.

Table (2) Properties of Glass Powder Compared with ASTM C-618 [19].

Chemical Composition of Components	)%Value(	Requirements According to the ASTM C-618 Specification Class N
Chemical Properties		
SiO_2	84.862	70 ≤
Al_2O_3	5.529	
Fe_2O_3	0.311	
CaO	7.934	---
SO_3	0.036	4 ≥
K_2O	1.251	---
TiO_2	0.037	---
ZrO2	0.011	---
Cr_2O_3	0.010	---
SrO	0.008	---
CuO	0.006	---
PbO	0.003	---
ZnO	0.002	---
Physical Properties		
Retained on a Sieve 45 µm(%)	9.88	34 ≥
Fineness(Blain Method) After 10 Minutes Grinding (cm^2/gm)	7340	---
Specific Gravity	2.265	---
L.O.I (Loss on Ignition) (%)	0.41	10 ≥
Strength Activity Index (%) 7 days 28 days	 80.7 81	 75 ≤ 75 ≤

Experimental Tests
Different tests were carried out in this investigation including:
Slump Test
The workability of concrete mixes was measured directly after mixing, according to ASTM C143 [24].

Fresh Density

The fresh unit weight of concrete was computed directly after mixing according to ASTM C 138M-01[25].

Oven Dry Density

The oven dry density of the concrete at 60 days age was carried out according to ASTM C642-13 [26].

Water Absorption

Water absorption test was conducted according to ASTM C642 [26].

Compressive Strength

The compressive strength test was carried out on concrete cubes specimens of 100 mm according to BS 1881: part 116[27].

III. RESULT & DISCUSSION

Selection of Mix Proportions for the Reference Concrete Mix.

Reference concrete mix was designed in according to British method for concrete mix design [28], to obtain concrete with minimum compressive strength of 40 MPa at 28 days without any admixtures. The mix proportions were 1:1.4:1.8 (cement: sand: gravel) by weight with cement content 500 kg/m^3, w/c ratio of 0.42 and slump value of 100±5 mm. Several trial mixes were carried out to select the optimum dosage of high range water reducing admixture (HRWRA). The w/c ratio was adjusted to have the same workability of the reference mix (slump of 100±5 mm). The main task of using HRWRA is to reduce the quantity of mixing water, while keeping the same workability of reference mix. According to the manufacturer the recommended dosage of HRWRA is between 0.5 and 2.5 liters per 100kg of cement. The experimental results in this study indicate that the optimum dosage of HRWRA is 1.5 liters per 100 kg of cement which leads to, a water reduction of about 35.71% and maximum compressive strength of 59.6 MPa at age 28 days. The details of the designed reference concrete mix containing various dosages of super plasticizer (HRWRA) are given in Table (3) and shown in Figures (3) and (4). It can be seen that HRWRA leads to a significant improvement compressive strength and causes a reduction in water cement ratio in comparison with the reference mix. This is due to the action mode of the superplasticizer, that when it is added to cement water system, the polar chain is adsorbed on the surface of cement particles. These surfactants give strong negative charge around the grain lowering the inter particles attraction by an electrostatic mechanism and produces amount of water consequently; lower amount of water is required to attain equal workability [29].

Table (3) Properties of Concrete Mixtures Containing Different Dosages of Superplasticizer.

Mix Proportions by Weight	Dosage of HRWRA (liter/100kg of Cement)	w/c Ratio	Slump (mm)	Water Reduction (%)	Compressive Strength (MPa)	
					7 days	28 days
1:1.19:1.8 Cement : sand : Gravel with Cement Content of 500kg/m^3	0	0.42	95	--	28.9	40.46
	0.5	0.36	102	14.28	38.1	48.6
	1	0.3	104	28.57	41.5	53.8
	1.5	0.27	102	35.71	47.7	59.6
	2	0.28	102	33.34	43.2	55.2

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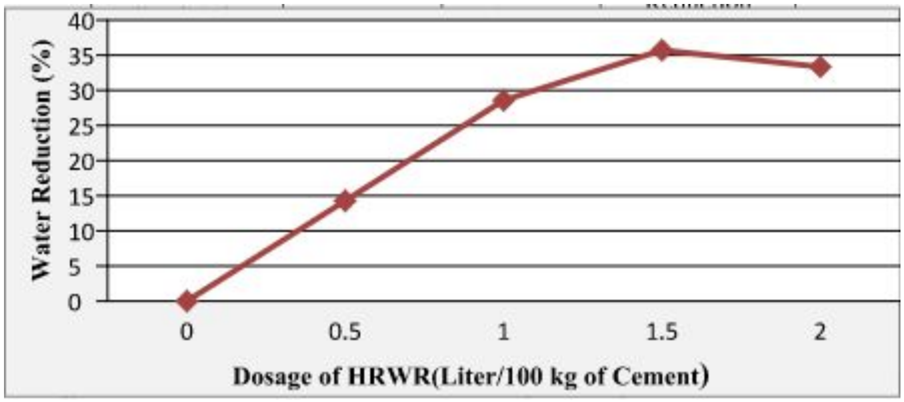

Figure (3) The Relationship between the Different Dosages of HRWRA and Water Reduction of Concrete Mix.

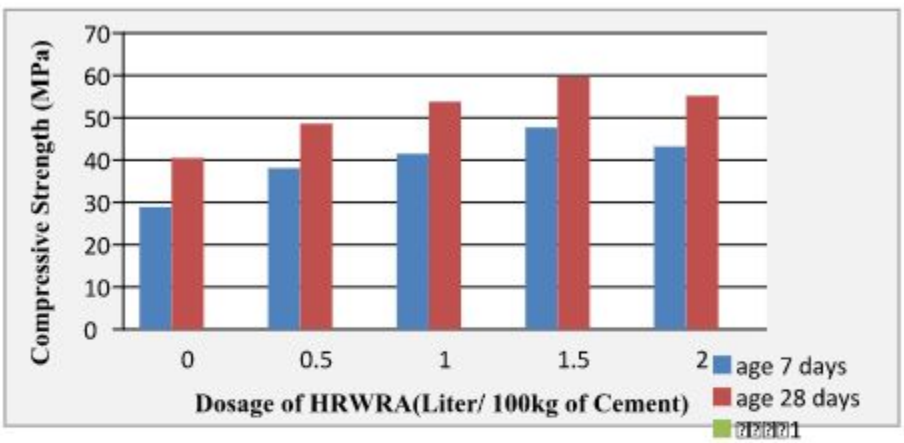

Figure (4) The Effect of Adding Different Dosages of HRWRA on the Compressive Strength of Concrete.

Properties of Concrete Containing Glass Waste Powder

Workability

The test results in Table (4) show the water reduction of fresh concrete with different percentages of glass powder as a partial replacement to cement. There is a tidy increase in water reduction with the increase of glass powder content for all mixes with the same workability (slump 100±5 mm) .This is due to the low water absorption of glass as a compared with cement [30].

Fresh Density

In general, tests results in Table (4) shows a slight decrease in the fresh density with the increase of glass powder content compared with the reference mix (without glass powder). This is due to the low specific gravity of glass powder 2.265 compared with the specific gravity of cement 3.15.

Oven Dry Density of Concrete

The test results at 60 days age presented in Table (4) show a slight increase in dry density for specimens containing glass powder up to 25%. The maximum increase is 1.671% for concrete with 15% glass powder as replacement to cement by weight. This increment is due to the change of calcium hydroxide ions that have specific gravity of 2.24 to extra gel with specific gravity of 2.3-2.6 [6,31]. The extra gel fills the space between particles in the microstructure of concrete that contribute to density increment. The slight decrease in oven dry density with 30% glass powder relative to reference may be due to formation more pores in microstructure of concrete in presence of high percentage of free silica as a replacement to cement.

Water Absorption of Concrete

Table (4) and Figure (5) showed the water absorption of different concrete specimens containing various percentages of glass powder at 60 days age. It's clear that the water absorption was decreased for concrete containing 10% and 15% glass powder by 3.98% and 9.75% respectively in comparison with the reference specimens, while the water absorption of specimens with 20% glass powder slightly increased but it is still slightly lower than that for reference specimens. Concrete specimens containing 25% and 30% glass powder have water absorption higher than that for reference specimens by about 1.51%, 4.5%. Generally concrete specimens containing 15% glass powder showed the lowest water absorption. The reduction in water absorption for concrete containing glass powder waste is due to the pozzolanic reaction between the active silica and calcium hydroxide. This reaction produces extra gel, which fill the space between particles, as well as segmented the continuous capillary pores in the microstructure of concrete, that reduces permeability consequently, thus decreases the absorption [3]. The increase of water absorption with the increase of glass powder content in concrete more than 15% is may be due to survival of free silica in the microstructure of concrete which causes weakness in the bond between various components of concrete

Table (4) Absorption, Fresh density, Oven Dry Density ofDifferent Concrete Mixes

Mix Symbol	Glass Powder as Replacement to Cement (%)	w/c Ratio	Slump (mm)	Water Reduction (%)	Fresh Density (kg/m^3)	Oven dry Density at 60 days (kg/m^3)	Water Absorption at 60 days (%)
R	--	0.270	102	--	2496.4	2303.4	0.728
GP10	10	0.266	104	1.5	2489.1	2325.0	0.699
GP15	15	0.260	101	3.7	2484.6	2341.9	0.657
GP20	20	0.256	102	5.2	2481.8	2314.5	0.722
GP25	25	0.254	103	5.9	2476.5	2306.3	0.739
GP30	30	0.250	102	7.4	2472.1	2300.2	0.761

Compressive Strength

The effect of different percentages of glass powder as a partial replacement by weight of cement (10%, 15%, 20%, 25%, and 30%) on the concrete compressive strength at different ages (7, 28, 60, and 90) days is shown in Table (5) and Figure (6). The test results demonstrate that the reference concrete is high strength concrete according to ACI 363 [32] that has a compressive strength of 59.6 N/mm^2 at 28 days. The compressive strength increases with the maturity age of concrete. This is due to the hydration of cement and the production of gel (C-S-H) and other hydration products of cement [33].The compressive strength of concrete containing different percentages of glass powder at 7 days age was reduced compared with the reference specimens(without glass powder). This reduction in strength is due to the fact of slow pozzolanic reaction that occurs between the reactive silica in glass powder and calcium hydroxide produced from the hydration of cement. This reaction produce extra gel that increases the strength at later ages [30, 33, 34, 35]. The test results have showed that the compressive strength at 28 and 60 days was increased for specimens containing 10% and 15% glass powder as a replacement to cement by weight. When the content of glass powder increases more than 15%, the compressive strength is reduced compared with reference specimen. This reduction may be because the increase of glass powder above the optimum percentage increases the active silica in the microstructure with depletion calcium hydroxide as a result of pozzolanic reaction. The remaining amount of free silica may be a weakness factor in the concrete structure .The test results showed that specimens containing 15% glass powder as a replacement to cement gave higher compressive strength with percentages increase of 1.17%, 13.3%, and 19.34% for 28, 60, and 90 days age compared with the reference specimens . It can be demonstrated that the difference between the percentages increasing of compressive strength at 28 and 60 days age are 12.13%, while between 60 and 90 days age is only 6%.In order to achieve sustainability in the practical and economical cases, therefore the strength at 60 days age for concrete containing 15% glass powder is considered as optimum value for practice applications.

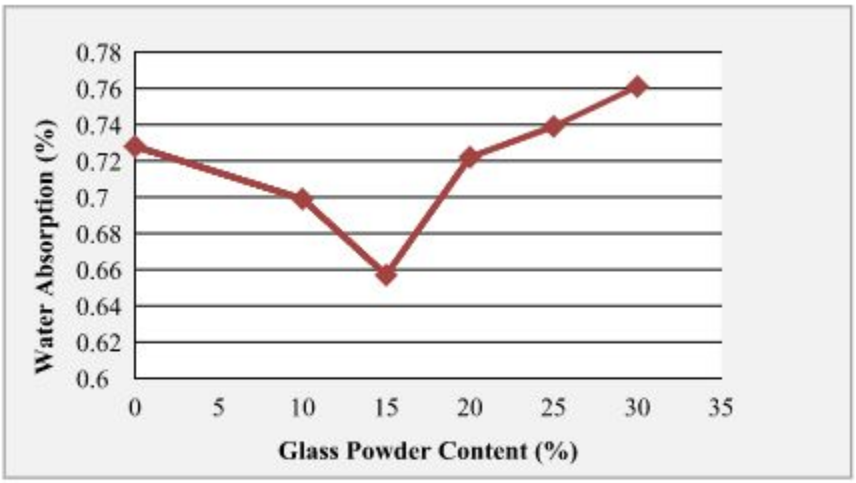

Figure (5) The Effect of Glass Powder Content on Water Absorption of Concrete

Table (5) The Effect of Glass Powder Content on the Compressive Strength of Concrete

Mix Proportions	Mix Symbol	The Proportion of Waste Glass Powder as Replacing by Weight from Cement (%)	Compressive Strength (N/mm^2)			
			7 days	28 days	60 days	90 days
1:1.19:1.8(Cement :Sand: Gravel) by weight with Cement Content of 500 kg/m^3, w/c ratio = 0.27, HRWRA= 1.5 %L/100 kg of Cement	R	0	47.7	59.6	64.7	66.2
	GP10	10	41.8	59.8	66.1	70.5
	GP15	15	44.4	60.3	73.3	79.0
	GP20	20	41.3	55.8	63.5	68.8
	GP25	25	38.5	53.1	60.0	65.5
	GP30	30	31.1	49.3	58.4	60.6

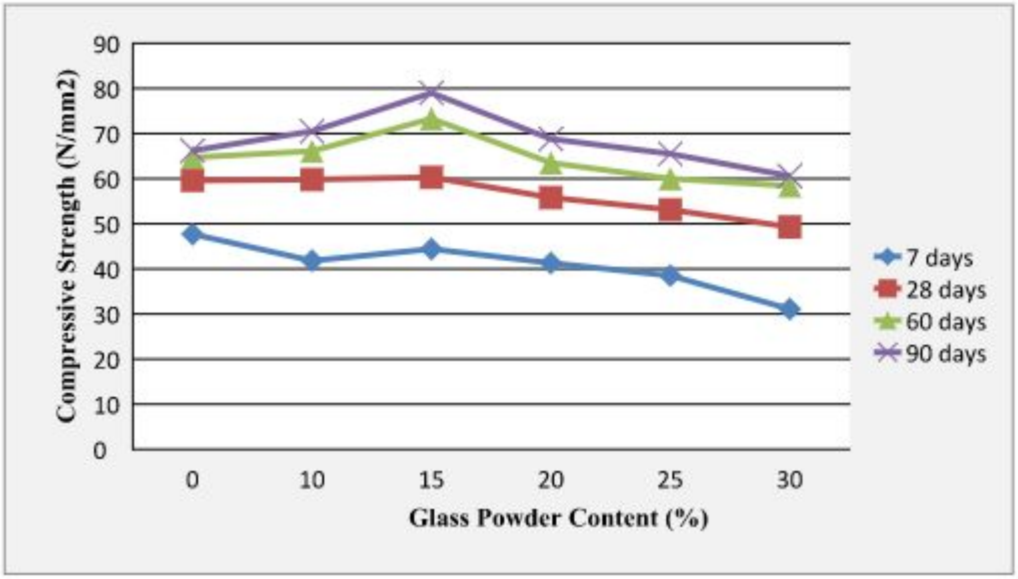

Figure (6) Relationship between Glass Powder Content and the Compressive Strength of Concrete.

IV. CONCLUSION

- Glass powder with particles size (≤75 micron) can be used as a partial replacement to cement in concrete, and behaves as naturala pozzolanic material that satisfiesthe requirements of ASTM C618.
- The fresh density is slightly decreased for all percentages of glass powder in concrete, while the oven dry density is slightly increased with the increase of glass powder content up to 25% at 60 days agecompared with the reference specimens without glass powder.
- The use of glass powder content of 15% as a replacement by weight of cement improvesthe compressive strength at later ages.The percentages increases are 1.17%, 13.34%, and 19.34% at 28, 60, and 90 days age respectively.
- The increase of glass powder content to 20% as replacement by weight of cement gives an increase in compressive strength of 3.93% at 90 days age, while the increase in glass powder over this content causes a decrease in compressive strength for all ages.
- Concretespecimens containing different content of glass powder up to 15% shows a decrease in water absorption, then water absorption is increased with the increase of glass powder content compared with the reference concrete.

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