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Some Properties of High Strength Sustainable Concrete Containing Glass Powder Waste

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Abstract

This investigation includes the use of glass wastes after recycling to produce high strength sustainable concrete. The glass waste used is prepared to be a natural Pozzolan class (N) according to ASTM C618 with fineness of about 7340 cm^2/gm. Many concrete mixes with different percentages of glass waste powder as a partial replacement by weight of cement (10%, 15%, 20%, 25%, and 30%) were prepared to study some properties of concrete (compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity at 60 day age). The test results indicate that the mechanical properties of concrete are improved with the increase of glass waste powder up to 15%, and then decreased. The maximum percentages of increase for compressive, splitting tensile, flexural strengths, and modulus of elasticity are 13.29%, 36.27%, 34.68%, and 8.2% respectively relative to the reference for concrete specimens containing 15% glass waste powder as a replacement by weight of cement.
Corrosion inhibition of low carbon steel, stainless steel types 316 and 304 in hydrochloric acid by potassium iodide was investigated at different temperatures using weight loss and polarization electrochemical techniques

Keywords: high strength concrete, sustainable concrete, glass waste powder.
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1- Introduction

High energy is needed to produce cement, which release large amounts of carbon dioxide CO_2. Also, large amount of glass waste are disposed in landfill sites because of the large use of these products that leads to increase costs and environmental problems. The environmental advantages of glass powder that used as a replacement to cement including, conversion of non-recycled waste glass from landfills to useful applications, reduction the negative effects of cement production such as the consumption of natural resources, reducing energy and the emission of greenhouse gasses, improving concrete mechanical properties, and reducing the cost of concrete industry. Therefore the use of recycled glass waste in concrete instead of cement gives a lot of interest [1, 2]. Early researches focused on the use of glass waste in concrete as partial or full replacement to fine or coarse aggregate. These early trails are unsuccessful because of the alkali- silica reaction (ASR) which takes place between glass waste and concrete and leads to deterioration of concrete with time [3, 4, 5, 6]. In order to overcome the alkali- silica reaction several treatment methods were used including, mechanical method by reducing the particle size of glass waste, or chemical method by using lithium compound to reduce the alkali- silica reaction expansion.

Keryon [6] used the local glass waste from windows glass with different percentages of 0%, 20%, 25%, and 30% as a partial replacement to coarse aggregate by weight. The results indicate that using glass waste leads to a decrease in the fresh density and slump values, while the compressive strength, flexural strength and splitting tensile strength are enhanced. The optimum percentage of replacement is 25% by weight. At this percentage, the increase in the compressive strength, splitting strength, and flexural strength are 30%, 38%, and 31% respectively relative to the reference specimens without glass waste.

Al-Obeidy and Khalil [7] investigated the effect of glass waste powder as a partial replacement to cement (by weight) on some properties of concrete. The different percentages of glass waste (10%, 15%, 20%, 25%, and 30%) were conducted to study the properties of concrete such as, fresh density, compressive strength at 7, 28, 60, and 90 day age, and water absorption at 60 day age relative to the reference concrete mix specimens without glass waste powder. The compressive strength for concrete specimens with 10%, 15% glass waste powder at 28, and 60 day age is increased. As the content of glass waste powder is increased to 20%, 25%, and 30%, the compressive strength is decreased. The maximum percentages increase in compressive strength are 1.17%, 13.3%, 19.34% for specimens with 15% glass powder waste at 28, 60 and 90 day age respectively, while the water absorption is decreased. The optimum percentage of glass powder is 15% as a partial replacement to cement, while the practical time of curing is 60 days age. This research provides the use of glass waste after grinding to particle size less than 75 µm as a replacement of cement by 15% in concrete and investigated its other properties at 60 day age.

2- Experimental Program

Properties of Materials

Cement

Ordinary Portland cement type (I) with commercial mark (Al Mass) was used in this investigation. The test results show that the cement used is compatible with Iraqi Standards No. 5 /1984. The cement is protected in sealed plastic containers to avoid exposure to the weather. The chemical and physical properties of the cement used are given in Tables 1 and 2 respectively.

Natural Fine Aggregate

Natural sand brought from Al-Ukhaider region with maximum aggregate size of 4.75mm was used. The sieve analysis and physical properties of this fine aggregate are presented in Table 3. The test results demonstrate that the used fine aggregate is within the requirements of the Iraqi Standard No.45/1980.

Natural Coarse Aggregate

Natural crushed coarse aggregate of nominal maximum size of 14 mm was used in this study. It was brought from AL–Badrah region. The properties of the natural coarse aggregate used are shown in Table 4. The results indicate that the grading and sulphate content of the coarse aggregate satisfy the requirements of Iraqi Standard No. 45/ 1980.

Water

The water used for mixing and curing of concrete was potable water from the water supply network (tap water).

High-Range Water Reducing Admixture

A 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 is compatible with ASTM C494-04 type F. Table 5 gives the main properties of this superplasticizer.

Glass Powder Waste Preparation

White glass were collected, washed, broken into small pieces, crushed and grinded into powder as shown in Figure 1.

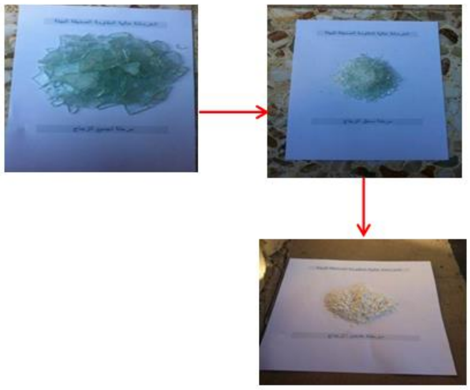

Figure 1: Preparation of Glass Powder.

Properties of Glass Powder

In previous research [7], the properties of the prepared glass powder were investigated. The results show that the fineness of the glass powder is 7340 cm^2/gm tested accordance to ASTM C-204 (Blain method). The results in Table 6 show, that 10 minutes grinding period gives the highest fineness for glass waste powder. The results in Table 7 show the strength activity index of glass waste powder at 28 day age is 81%, The remaining on sieve 45 microns (No. 325) is 9.88% , and the amount of silica and alumina with the ferric oxides is about 90% are within the limits of ASTM C-618. The specific gravity of glass powder is 2.265. According to these results glass waste powder is classified as a natural Pozzolan according to ASTM C618.

Selection of Mix Proportions for the Reference Concrete Mix

In previous research [7], reference concrete mix was designed in according to British method for concrete mix design, to obtain concrete with minimum compressive strength of 40 MPa at 28 day age without any admixtures. The mix proportions are 1:1.4:1.8 (cement: sand: gravel) by weight, with cement content of 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. The details of the designed reference concrete mix containing various dosages of superplasticizer (HRWRA) are given in Table 8 and shown in Figure 2.

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 investigation 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 day. The optimum dosage of high range water reducer which gives the highest compressive strength is 1.5% / 100 kg cement.

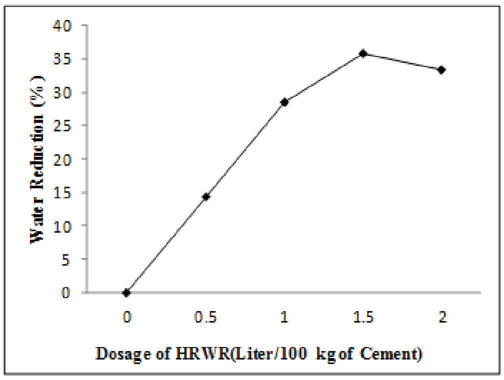

Figure 2: Relationship Between the Different Dosages of HRWRA and Water Reduction of Concrete Mix

Mixing, Casting and Curing of Concrete Specimens

The mixing process was performed in an electrical rotary vessel mixer of $0.1m^3$ 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 added to the mix and mixed for two minutes.

The steel molds were cleaned and their internal surfaces were lubricated with oil. The molds were filled with concrete and compacted by a vibrating table according to ASTM C-192/C192M, to remove any entrapped air. After compaction, the specimens were leveled by hand troweling, covered with polyethylene, and left for 24 hours. The specimens were removed from molds, and they were completely submerged in water containing 3gm/liter of calcium hydroxide according to ASTM C511. Concrete specimens were cured till the time of test.

Experimental Tests

The experimental tests that carried out in this investigate are the followings:

- Compressive, strength test according to B.S. 1881. This test was carried out on concrete cubes specimens of 100 mm. The average value of three specimens was recorded for each concrete mix at 60 day age.

- Splitting tensile strength test according to ASTM C496. The average splitting tensile strength value for three cylinders (200mm height and 100 mm diameter) was computed at 60 day age.

- Flexural strength (modulus of rupture) test under two point loads according to ASTM C78. The average modulus of rupture for three prismatic specimens (100 x 100 x 400 mm) was computed at 60 day age.

- Static modulus of elasticity test was carried out according to ASTM C469. Three Concrete cylinders of 300 mm height and 150 mm diameter were tested at 60 day age and the average value was calculated.

Results and Discussion

Compressive Strength

The test results in Table 9 and Figure 3 show that the reference concrete (without glass powder) prepared in this investigation is high strength concrete with compressive strength of 64.7 MPa at 60 day age [8]. The compressive strength increases to 66.1 and 73.3 MPa for specimens containing 10% and 15% glass powder as a replacement to cement by weight respectively at 60 day age. When the percentage of glass powder is increased over 15%, the compressive strength is reduced compared with the reference specimens. The increase of compressive strength is due to the pozzolanic reaction that has been occurred, as a result of this reaction additional gel is produced, and thus the strength is improved[9,10]. The increase of glass powder above the optimum content (15%) may be leads to increase the active silica in the microstructure of concrete with the depletion of calcium hydroxide as a result of pozzolanic reaction. The remaining amount of free silica may cause weakness in the concrete structure and reduces the strength. The test results show that concrete specimens with 15% glass powder as a replacement of cement gave the maximum compressive strength.

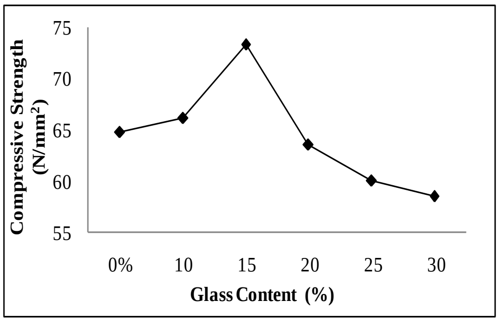

Figure 3: Effect of Glass Powder Content on the Compressive Strength of Concrete.

Splitting Tensile Strength

Values of splitting tensile strength at 60 day age of concrete specimens with various percentages of glass powder as partial replacement to cement are shown in Table 9 and Figure 4. The results demonstrate a clear increase in splitting tensile strength of concrete containing 10%, 15%, and 20% glass powder of about 3.27%, 36.27%, and 23.17% respectively compared with the reference concrete. This is due to the formation of extra gel from the pozzolanic reaction, in addition, glass powder fills the spaces between particles and increase the bond strength between the components of concrete[10, 11]. When the percentage replacement of glass powder increases to 25%, 30%, the tensile strength reduces by about 11.33%, 19.14% respectively relative to the reference. This may be due to the reaction of calcium hydroxide with part of silica in glass powder and the survival amount of free silica in the microstructure of concrete reduces the bond between concrete components. The maximum splitting tensile strength is recorded for concrete containing 15% glass powder as a replacement by weight of cement.

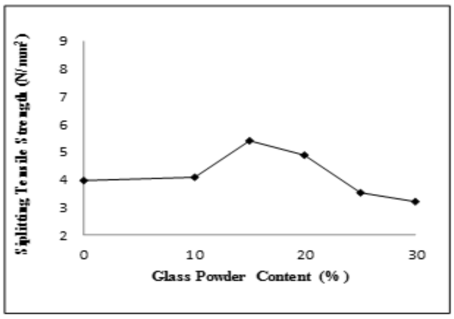

Figure 4: Effect of Glass Powder Content on Splitting Tensile Strength of Concrete.

Flexural Strength

The flexural strength results of concrete at 60 day age with different percentages of glass powder are presented in Table 9 and Figure 5. The results indicate that the flexural strength increases for concrete containing 10%, 15%, and 20% glass powder as a partial replacement of cement by weight. The highest increment is 34.68 % for specimens with 15% glass powder compared with the reference. This increase is because glass powder improves the transition zone between aggregate and cement paste consequently due to the pozzolanic reaction, as well as its filling ability to the voids in the microstructure of concrete by extra gel produced from this reactions that reduces the porosity, which is inversely proportion with the strength of concrete [12, 13]. The reduction of flexural strength for specimens with 25% and 30% of glass powder are 12.23% and 18.84 % respectively. This may be attributed to the depletion of calcium hydroxide due to the pozzolanic reaction. The survival part of free silica in the microstructure of concrete may be reduces the strength and the bond between the components of concrete. Concrete containing 15% glass powder has the maximum flexural strength.

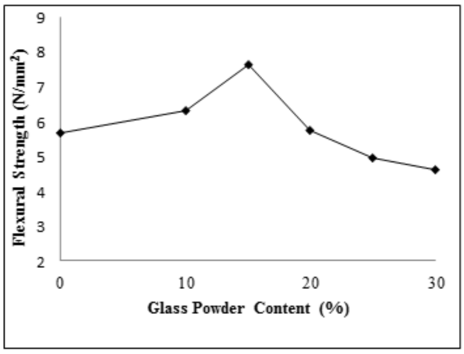

Figure 5: Effect of Glass Powder Content on Flexural Strength of Concrete.

Static Modulus of Elasticity

Table 9 and Figure 6 show the values of static modulus of elasticity for concrete with different percentages of glass powder as a replacement to cement at 60 day age. The results indicate a slight increase in modulus of elasticity for specimens containing 10%, 15%, and 20% glass powder relative to the reference. The highest increment (8.2%) in modulus of elasticity is for specimens with 15% glass powder. This is because there is a direct relationship between the compressive strength and modulus of elasticity [9, 13]. The increase in content of glass powder to 25% and 30 % causes a slight reduction in modulus of elasticity of about 3.1% and 7.92% respectively. This is because the compressive strength is also decreased.

Generally, all the results show that the optimum content of glass powder which improves the properties of concrete is 15% as a replacement by weight of cement.

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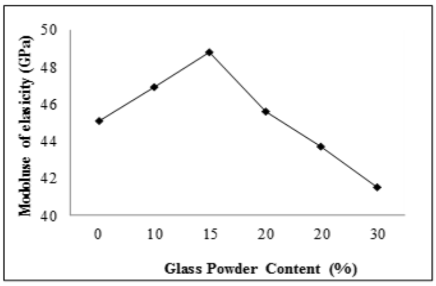

Figure 6: Effect of Glass Powder Content on the Static Modulus of Elasticity of Concrete.

Conclusion

The following conclusions can be drawn from the experimental results presented in this investigation:

1- Glass powder with particles size less than75 micron behaves as a natural pozzolanic material type (N) that improves the mechanical properties of concrete.

2- The use of glass powder as a replacement by weight of cement up to 15% increases the compressive strength at later ages (60 day age). The increment percentages are 2.16% and 13.29% for specimens containing 10% and 15% glass powder respectively relative to the reference specimens.

3- The increase of glass powder content more than 15% shows reduction in compressive strength of concrete. The percentages reduction are 1.85%, 7.26%, and 9.73% for concrete specimens with 20%, 25%, and 30% glass powder respectively compared with the reference specimens.

4- The use of glass powder as a replacement by weight of cement up to 20% enhances the, splitting tensile strength, flexural strength, and static modulus of elasticity of concrete in comparison with the reference specimens, while the increase of glass powder content more than 20% decreases all these properties.

6- The optimum content of glass powder in concrete is 15% as a replacement by weight of cement. The percentages increase in compressive strength, splitting tensile strength, flexural strength, and static modulus of elasticity of concrete containing 15% glass powder are 13.29%, 36.27%, 34.68%, and 8.2% respectively relative to the reference concrete.

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Table 1 Chemical Composition and the Main Compounds of Cement Used in this Investigation.*

Oxide Composition	Content (%)	Limits of Iraqi Standard No. 5/1984
Lime (CaO)	64.62	--
Silica Dioxide (SiO_2)	20.53	--
Alumina Trioxide (Al_2O_3)	4.57	--
Iron Oxide (Fe_2O_3)	2.97	--
Magnesia Oxide (MgO)	1.66	≤ 5.0%
Sulphate (SO_3)	2.52	≤ 2.8 if C_3A ≥5.0%
Loss on Ignition (L. O. I.)	2.10	≤4.0%
Insoluble Residue (I. R.)	0.41	≤ 1.5%
Lime Saturation Factor (L. S. F.)	0.62	0.66-1.02
Main Compounds (Bogue's equations)		
Tricalcium Silicate (C_3S)	49.81	--
Dicalcium Silicate (C_2S)	24.49	--
Tricalcium Aluminate (C_3A)	7.44	--
Tetracalcium Alumino-Ferrite (C_4AF)	10.19	--

*Tests were carried out in the National Center for Construction Laboratories.

Table 2 Physical Properties of Cement Used Throughout this Investigation.*

Limits of Iraqi Standard No.5/1984	Test Results	Physical Properties
≥ 2300	3760	Specific Surface Area, Blaine Method (cm²/gm).
 ≥ 45 min ≤ 10 hrs.	 2:35 4:20	Setting Time : -Initial Setting (hrs.: min) -Final Setting (hrs.: min)
  ≥ 15 ≥23	 29.5 32.6	Compressive Strength of Mortar (MPa): 3-days 7-days
≤ 0.8	-0.024	Soundness % (Autoclave)

*Tests were carried out in the National Center for Construction Laboratories.

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Table 3 Grading and Properties of Natural Fine Aggregate Used in this Investigation.*

Sieve size (mm) According to Iraqi Standard No.23	Percentage Passing	Limits of Iraqi Standard No. 45/1980 Zone(2)
10	100	100
4.75	100	90-100
2.36	88	75-100
1.18	78	55-90
0.6	56	35-59
0.3	19	8-30
0.15	5	0-10
Physical Properties and Others		
Material Passing Sieve 75µm (%)	2	≤ 5%
Sulphate Content (%)	0.3921	≤ 0.5%
Fineness Modulus	2.54	--
Absorption (%)	2	--
Specific Gravity	2.65	--
Bulk Density(kg/m^3)	1559	--

*Tests were carried out in the National Center for Construction Laboratories.

Table 4 Grading and Properties of Natural Coarse Aggregate.*

Sieve Size (mm)According to Iraqi Standard No.23	Cumulative Passing (%)	Limits of Iraqi Standard No. 45 / 1984with (5-14)mm
14	100	100
10	72	50-85
5	0	0-10
Other Properties		
Dry Rodded Density (gm/cm^3)	1715	--
Specific Gravity	2.63	--
Sulphate Content (%)	0.063	≤ 0.1
Absorption (%)	1.7	--

*Tests were carried out in the National Center for Construction Laboratories.

Table 5 Properties of High Range Water Reducer. *

Physical and Chemical Properties	Description
Appearance	Whitish to straw colored liquid
Specific Gravity	1.07
Chloride Content	Nil
PH	5-8
Solid Content (%)[1*]	35.6

*According to manufacturer

1*Tests were carried out in the National Center for Construction Laboratories.

Table 6 Fineness of Crushing Glass Waste Powder after Different Grinding periods.*

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

*Tests were carried out in the National Center for Construction Laboratories.

Table 7 Properties of Glass Powder [7]*

Chemical Composition of Components	Value(%)	Requirements of ASTM C-618 Specifications 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 (%)[*1]	9.88	≤ 34
Fineness(Blain Method) After 10 Minutes Grinding (cm^2/gm)	7340	---
Specific Gravity	2.265	---
Loss on Ignition L.O.I (%)	0.41	≤ 10
Strength Activity Index (%)[*2] 7 days 28 days	 80.7 81	 ≥ 75 ≥ 75

*Tests were carried out in the National Center for Construction Laboratories.

*1Tests were carried out in the Central Organization for Standardization and Quality.

*2 Test were carried out in the laboratory of Building and Construction, Engineering Department/ University of Technology.

Table 8 Experimental Concrete Mixtures Containing Different Dosages of Superplasticizer.* [7]

Mix Proportions by Weight	Dosage of HRWRA (liter/100kg of Cement)	w/c Ratio	Slump (mm)	Water Reduction (%)	Compressive Strength (MPa)	
					7 days	28 day
Cement : sand : Gravel with Cement Content of 500kg/m^3 :1:1.4:1.8	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

*Tests were carried out in the National Center for Construction Laboratories.

Table (9) Compressive, Splitting Tensile, Flexural Strengths, and Static Modulus of Elasticity for Various Concrete Mixes

Mix Symbol	Name of Symbol	Compressive Strength at 60 days (N/mm^2)	The Percentage Change in the Compressive strength	Splitting Tensile Strength at 60 Days (N/mm^2)	The Percentage Change in the Splitting Tensile Strength	Flexural Strength at 60 Days (N/mm^2)	The Percentage Change in the Flexural Strength	Static Modulus of Elasticity at 60 Days (kN/mm^2)	The Percentage Change in the Modulus of Elasticity
R	Reference	64.7	---	3.97	---	5.68	---	45.1	---
GP10	Concrete Containing 10% Glass Powder as a Replacement of Cement	66.1	+2.16	4.1	+ 3.27	6.34	+11.62	46.9	+ 3.99
GP15	Concrete Containing 15% Glass Powder as a Replacement of Cement	73.3	13.29 +	5.41	+36.27	7.65	+34.68	48.8	+8.20
GP20	Concrete Containing 20% Glass Powder as a Replacement of Cement	63.5	- 1.85	4.89	+23.17	5.75	+ 1.23	45.6	+ 1.11
GP25	Concrete Containing 25% Glass Powder as a Replacement of Cement	60.0	- 7.26	3.52	-11.33	4.98	-12.23	43.7	- 3.10
GP30	Concrete Containing 30% Glass Powder as a Replacement of Cement	58.4	- 9.73	3.21	-19.14	4.61	-18.84	41.53	-7.92