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 cm²/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. 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 trials 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.

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 CO₂. 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.
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.

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 cm²/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/m³, 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.

**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 2**: Relationship Between the Different Dosages of HRWRA and Water Reduction of Concrete Mix
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. 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.
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 than 75 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.

5. 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 (SiO₂)     | 20.53       | --                                  |
| Alumina Trioxide (Al₂O₃) | 4.57        | --                                  |
| Iron Oxide (Fe₂O₃)        | 2.97        | --                                  |
| Magnesia Oxide (MgO)      | 1.66        | ≤ 5.0%                              |
| Sulphate (SO₃)            | 2.52        | ≤ 2.8 if C₃A ≥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)

| Physical Properties       | Test Results | Specific Surface Area, Blaine Method (cm²/gm). |
|---------------------------|--------------|------------------------------------------------|
| Setting Time:             |              | -Initial Setting (hrs.: min)                    |
|                          |              | -Final Setting (hrs.: min)                      |
| Compressive Strength of Mortar (MPa): |              | 3-days                                           |
|                          |              | 7-days                                           |
| Soundness % (Autoclave)   |              | ≤ 0.8 -0.024                                     |

*Tests were carried out in the National Center for Construction Laboratories.
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/m³): 1559

*S: 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/cm³): 1715
- Specific Gravity: 2.63
- Sulphate Content (%): 0.063 ≤ 0.1
- Absorption (%): 1.7

*S: 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 (%)               | 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) cm²/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              |          |                                                  |
| SiO₂                              | 84.862   | ≥ 70                                             |
| Al₂O₃                             | 5.529    |                                                  |
| Fe₂O₃                             | 0.311    |                                                  |
| CaO                               | 7.934    | ---                                              |
| SO₃                               | 0.036    | ≤ 4                                              |
| K₂O                               | 1.251    | ---                                              |
| TiO₂                              | 0.037    | ---                                              |
| ZrO₂                              | 0.011    | ---                                              |
| Cr₂O₃                             | 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 (cm²/gm) | 7340 | --- |
| Specific Gravity                  | 2.265    | ---                                              |
| Loss on Ignition L.O.I (%)        | 0.41     | ≤ 10                                             |
| Strength Activity Index (%)*2     |          |                                                  |
| 7 days                            | 80.7     | ≥ 75                                             |
| 28 days                           | 81       | ≥ 75                                             |

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

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

2* Tests 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.*

| 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                    |
| 1:4:1.8... (Cement : sand : Gravel with Cement Content of 500kg/m³) | 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/mm²) | The Percentage Change in the Compressive Strength | Splitting Tensile Strength at 60 Days (N/mm²) | The Percentage Change in the Splitting Tensile Strength | Flexural Strength at 60 Days (N/mm²) | The Percentage Change in the Flexural Strength | Static Modulus of Elasticity at 60 Days (kN/mm²) | 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                                       | 41.5/3                                         | -7.92                                         |