Mechanical Properties, Energy Impact Capacity and Bond Resistance of concrete incorporating waste glass powder

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Abstract. The present study is investigated about effect of glass waste as powder as partial replacement of cement in some properties of concrete. These properties included compressive strength, splitting and flexural tensile strengths, impact resistance and bond strength. The effect of glass as powder was examined by compared to control specimens without glass powder replacement. Three percentage were tested: 0%(control), 10 and 15%. Results showed that using glass powder improved properties of concrete under different type of loading. Compressive strength increased by 26.34% and 22% when compared it with control mix for 10% and 15% glass powder, respectively. While splitting tensile strength increased by 23.5% and 28.7% more than control mix for 10% and 15% glass powder, respectively. And modulus of rupture increased by 17% and 10% for 10% and 15% glass powder, respectively. The impact resistance of mixes 10% and 15% of glass powder were increased by 14.3% and 4.76% in compression with control mix, respectively. Finally glass powder also improve bond strength where the ultimate bond strength increased by 4.7% and 6.2% for 10% and 15% glass powder respectively. Then the utilization of waste glass as powder in concrete reduced amount of cement and improved its resistance to load.

1. Introduction

Glass waste is one of the major environmental problems where millions of tons of glass waste is thrown annually in the wilderness and public utilities. In 2005, the quantity of glass waste is estimated at 130 million tons, about 20, 32 and 33 million tons in America, Europe and China, respectively [1]. There are many ways to get rid of the remnants of glass, including re-use waste glass as coarse aggregate in concrete, where many researchers dealt this subject [2, 3] and the others researched about using waste glass as fine aggregate in concrete [4,5]. In addition, waste glass can be used as powder (WGP) as cement replacement is the best method to reused waste glass because WGP work as pozzolanic material when its ground finely, as a result the concrete properties will modified and reducing cement consumption which represent the more expensive material in concrete on other hand, cement production process harms the environment by carbon regeneration which raised from cement production factories. According to ASTM C618 requirements, powdered soda-lime glass (window’s glass) may be categorized as Class N natural pozzolan if sodium oxide (Na2O) content in these glass powders is not a concern. The use of milled glass as a partial replacement of cement in concrete improves the mechanical properties of concrete and others. Tamanna et al., 2014 [6] examined the fineness effect of waste glass powder WGP on strength characteristics. Four sizes glass particles were used (212-150µm, 150-75µm, 75-38µm and less than 38µm). the WGP was replaced by (0%, 10%, 20%, 30% and 40%) percentage of cement. Mortars cubes were used for strength calculation with water to cement ratios 0.45 and 0.5. The result found that replacement of 10% cement with WGP
carried out the higher compressive strength at 28days compare with other levels of replacement. In addition, the finer WGP gives the higher strength due to pozzolanic effect of powdered glass which helps to increase the rate of WGP’s reaction with Ca(OH)2 which product C-S-H. Uary, 2016 [7] investigated the ability of WGP usage as partial cement replacement in concrete. The compressive, flexural, indirect tensile strength and elastic modulus of concrete containing WGP was carried out. The WGP were replaced by (5%, 10%, 15%, 20% and 25%) of total weight of cement. The results of this study have found that glass waste causes a pozzolanic strength of 82.3% making it appropriate pozzolanic material. The mechanical strength (flexural, indirect tensile and compressive strengths) in addition to elastic modulus of concrete were shown 10% of WGP replacement represent the optimum ratio which gives higher strength than the control concrete strength. Hama [8] found that using waste glass powder as partial replacement of cement led to improvement in mechanical properties of lightweight aggregate concrete. Yassen et al. [9, 10] studied the the effect of glass powder as cement replacement on fresh and hardened properties of concrete mixes. Compressive, flexural and splitting strengths of specimens contain glass powder showed increase compared to reference mix. splitting tensile strength, flexural strength and modulus of elasticity of mixes contained 15% waste glass powder showed best performance. Also the glass powder decreased water absorption capacity. Hama et. al. [11] investigated the flexural behaviour of reinforced concrete beam contain waste glass powder. They found that ultimate strength of the beam have increased especially at 15% glass powder replacement level.

2. Materials and Laboratory Work
The ordinary Portland cement (OPC) was used in this research which compatible to Iraqi Standards No. 5. [12] The specific gravity of cement was 3.5 and other properties were declared in Table 1 below:

| Test                           | Value       | Requirements of Iraqi standards |
|-------------------------------|-------------|---------------------------------|
| Fineness by Blaine method     | 233.72 kg/m² | >230kg/m³                       |
| Initial freezing by Vigat instrument | 51 min      | > 45min                         |
| Final freezing by Vigat instrument | 9.1 hours   | < 10 hours                      |
| Stability by autoclave method | 0.72%       | < 0.8%                          |

The gravel used in the mixtures was crushed and rolled according to the Iraqi specifications and the maximum size was 10 mm. Table 2 represent the grading of the gravel and the limits of the Iraqi Standards No. 45 [13]

| Sieve No.        | Passing | Requirements of Iraqi standards |
|------------------|---------|---------------------------------|
| 10 mm (3/8 in)   | 99%     | 85-100%                         |
| 5mm (4 in)       | 22%     | 0-25%                           |
| 2.36 mm (8 in)   | 2%      | 0-5%                            |
Table 3 shows the sieve analysis of the sand used for this research, which is clean and identical to the region 1 within the limits of the Iraqi Specifications No. 45. [13].

### Table 3. sieve analysis of sand in comparison with IQS No. 45

| Sieve size | Passing % | Region 1 limits |
|------------|-----------|-----------------|
| 10 mm      | 96.25%    | 100             |
| 4.75 mm    | 90.95%    | 90-100          |
| 2.36 mm    | 64.8%     | 60-95           |
| 1.18 mm    | 48.2%     | 30-70           |
| 0.6 mm     | 16.35%    | 15-34           |
| 0.3 mm     | 5.2%      | 5-20            |
| 0.15 mm    | 0.25%     | 1-0             |

Waste glass was collected from glass windows in our university where the glass was cleaned, washed, then gradually crushed and then crushed into a fine powder by an electric grinder. From the analysis of the glass powder shown in figure 1, the maximum size of the crushed glass granules is 150 microns while about 75 percent of the glass passes through a 75 micron sieve. Figure 2 illustrate the process of waste glass powder (WGP) preparing

![Figure 1. The grading of cement and powdered glass](image)

The specific gravity of using super plasticizer (Sika ViscoCrete® -5930) was 1.095 and the ratio of super plasticizer which used in mixes was 0.8% from the weight of cement.

### 3. Experimental Work

Three mixes were casted include the control mix, the 10% and 15% WGP mix which used as partial replacement of cement weight. The water / cement ratio (W/C) was 0.29 while the mix ratios of concrete gradient were 1: 2.13: 2.83 (cement: sand: gravel).

Six cylinders (300×150 mm) were made for each mix for compression and splitting tensile strengths tests for each mix, in addition, nine prisms (100×100×500 mm) were casted to examine flexural strength of concrete mixes.

Six cubes (100×100 mm) and six disks with 150 mm height and 50 mm thickness were casted to investigate pull out test and impact test, respectively where the pull out test and impact test were made according to ACI 544 [14] and specification [15], respectively while the compression, splitting tensile and flexural strengths were performed according to ASTM C39/C39M - 05, ASTM C496 and ASTM C293 specifications, respectively [16-18].
4. Result and Dissection

4.1. Compression Strength

The result showed an improvement of compression strength with addition of WGP. The strength increased by 26.34% and 22% when compared it with control mix for 10% and 15% of WGP mixes, respectively. Figure 3 was declared the strengths values. This improvement of strength because of a pozzolanic properties of WGP. The WGP perform as pozzolanic materials for particles less than 75 microns while the largest particles represent filler particles in concrete. The pozzolanic material produced C-S-H which filled cavities in cement paste including transition zone and that will improve compression strength and as a results the other mechanical properties. The mechanical properties results were compatible with [9] and [10] results.

![Figure 3. Variation of compression strength of concrete with WGP content](image)

**Figure 2.** Preparing of Waste glass powder
4.2. Splitting tensile strength

As appeared in figure 4 the splitting tensile was raised when a WGP was added where it increased by 23.5% and 28.7% more than control mix for 10% and 15% of WGP mixes, respectively. The experimental results was compared with calculating value according to suggestion equation for splitting strength in ACI 318 Code is $0.56\sqrt{f'_c}$ where the $f'_c$ is represent the compression strength of concrete cylinder at 28 days. The table 4 below was shown a comparative relation between ACI equation result and the splitting strength of the mixes where it was shown a good compatible result with ACI equation for 0% WGP and the difference increased with increasing WGP content.

| WGP% | $f'_c$ | Calculating $f_t$ according to ACI | Experimental $f_t$ | Experimental $f_t$ Calculating $f_t$ |
|------|--------|---------------------------------|-------------------|------------------------------------|
| 0%   | 42.9   | 3.67                            | 3.9               | 1.06                               |
| 10%  | 54.2   | 4.12                            | 4.82              | 1.17                               |
| 15%  | 52.34  | 4.05                            | 5.02              | 1.24                               |

Figure 4. Splitting tensile strength variation with WGP content

- **Flexural Strength.** The Flexural strength of concrete having WGP higher than the control mix where the 10% and 15% of WGP mixes increased by 17% and 10%, respectively. As shown in figure 5 below. The ACI 318 Code equation to calculate flexural strength is $0.62\sqrt{f'_c}$ . Table 5 was shown a comparison between the experimental flexural strength and calculating value according to ACI equation. The comparison was shown a good compatible results.
Table 5. The comparison between ACI flexural equation and experimental mixes values

| WGP% | \(f'_c\) | Calculating \(f_r\) according to ACI | Experimental \(f_r\) | Experimental \(f_r\) calculating \(f_r\) |
|------|---------|-------------------------------------|---------------------|-----------------------------|
| 0%   | 42.9    | 4.06                               | 4.42                | 1.09                        |
| 10%  | 54.2    | 4.56                               | 5.17                | 1.13                        |
| 15%  | 52.34   | 4.49                               | 4.86                | 1.08                        |

The statistical suggestion empirical equation for splitting and modulus of rupture were

\[
f'_t = 0.0817(f'_c)^{1.03} \text{ MPa} \quad \ldots \ldots (1)
\]

and

\[
f_r = 0.4544(f'_c)^{0.693} \text{ MPa} \quad \ldots \ldots (2)
\]

respectively with a coefficient of variation of \(R^2 = 0.9186\) for splitting strength and \(R^2 = 0.9322\) for flexural strength as described in Figure 6. The equations above make an acceptable relation that represent the improvement of splitting and flexural strengths with WGP addition.

**Figure 5.** Flexural Strength variation with WGP%
4.3. Impact test

The impact resistance of concrete decreased with increased WGP addition because of the effect of glass as powder increased concrete stiffness besides of increasing in compressive strength of concrete but that led to decrease in its ductility. Table 4 below showed the number of blows which concrete required to appear the first crack and number of blows which required to final failure. The energy absorbed by concrete can be calculating using the following equation:

$$EI = Nmgh \ldots \ldots$$

Where:
- $EI$: Impact Energy (N.m).
- $m$: mass of the drop hammer (4.536 Kg)
- $N$: The number of blows
- $g$: Gravity acceleration (9.81 N/Kg)
- $h$: Height of drop hammer (0.4572 m)

The impact resistance of mixes 10% and 15% of WGP were increased by 14.3% and 4.76% in compression with control mix, respectively and that clear by observing an increase in number of blows required to cause cracking and failure. The energy capacity of mixes 10% and 15% of WGP were increased to 4394.42 N.m and 4028.22 N.m in compression with control mix which has energy capacity of 3845.12 N.m.

| WGP% | First crack | Final crack | Impact energy N.m |
|------|-------------|-------------|-------------------|
| 0%   | 187         | 189         | 3845.12           |
| 10%  | 214         | 216         | 4394.42           |
| 15%  | 196         | 198         | 4028.22           |

4.4. Ultimate Bond Strength

The presence of WGP also improve bond strength where the ultimate bond strength increased by 4.7% and 6.2% for 10% WGP and 15% WGP mixes, respectively when comparing it with control mix. The figure 6 described ultimate bond strength.
An a proposed equation with $R^2 = 1$ was suggested based on experimental data to predict the bond strength of concrete which cement has partially replaced by glass powder as follow:

$$\text{Bond Strength} = -20.667\text{WGP}^2 + 9.9667\text{WGP} + 16.64 \quad \ldots\ldots(4)$$

5. **Conclusions**

As a summery, the following conclusions were made according to experimental results

1. Compressive strength was improved due to replaced cement partially by WGP. It increased by 26.34% and 22% compared with control mix for 10% and 15% glass powder, respectively.
2. Splitting tensile strength increased by 23.5% and 28.7% more than control mix for 10% and 15% glass powder, respectively. And modulus of rupture increased by 17% and 10% for 10% and 15% glass powder, respectively.
3. The number of blows required to failure of mixes 10% and 15% of glass powder were increased by 14.3% and 4.76 % in compression with control mix, respectively.
4. The ultimate bond strength between concrete and steel reinforcement increased by 4.7 % and 6.2 % for 10% and 15% glass powder respectively.

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