Behavior of sustainable Reactive Powder Concrete by Using Glass Powder as a Replacement of Cement

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Abstract: Every year, the world produces one million tons of glass garbage. Once the glass has been broken down, it is dumped in landfills, where it will remain inert for hundreds of years. Glass is mainly made of silica. For long-term infrastructure development, ground glass as a partial cement substitute may be a major advance (environmentally friendly, energy-saving, and economic). Secondary calcium silicate hydrate is expected to be produced when glass waste is crushed into microscopic particles and then reacts with cement hydrate through pozzolanic interactions (C-S-H). There were experiments done on concrete utilizing (0-35 per cent) ground glass and superplasticizer, silica fume, fine sand and fibres, with the water to binder (cement + glass) ratio maintained constant for all degrees of replacement on compressive strength, modulus of elasticity and tensile strength. Steel is a fixed quantity that applies to all conceivable configurations. Concrete cube samples were made and tested for strength (28 days curing). It was discovered that the recycled glass concrete outperformed control samples in compressive strength tests. Compressive strength, tensile strength, and modulus of elasticity are all greatest in the 25 per cent glass powder. It was decided that using recycled glass trash in place of 25 per cent of the cement was a good idea because of the economic and environmental advantages.

1. INTRODUCTION

Every country in the world has a significant issue with glass trash. Glass can create significant environmental contamination due to its non-biodegradable nature. Similarly, highly crowded cities in many areas across the globe suffer a shortage of room for new warehouses; as a result, this material took up a large portion of landfill space. The greatest way to lessen the effect of this glass trash on the environment is to reuse it. Recycling glass trash offers many environmental advantages, including the reduction of landfill space, energy savings, and cost savings [Al-jburi Najad A. A and Hasan Kareem (2019)] [1]. There are no physical or chemical changes to glass throughout the recycling process; thus, it may be recycled endlessly. In addition, since the crushed waste glass may create variations in the chemical composition of the recovered glass, the recycling process is impracticable and costly. As a result of impurities and pollutants present in the waste glass, it is possible that newly created glass may be adversely affected [Federico, L. M and Chidiac, S. E. (2009)][15]. Because of the carbon footprint involved with the cement production process, the concrete manufacturing process has major environmental implications. Due to the physical and chemical composition of sand-like glass and cement, cement is an essential and useful component for use in the environmental impacts of waste glass. Cement, a major component of concrete, is energy-intensive in production and accounts for about 85 per cent of the total concrete and cement industry that is a component of the building industry . [N. Sivakugan,2017] [2]. At 1500°C, a mixture of sodium carbonate, silica, limestone (CaCO3), and dolomite (CaMg (CO3)2) may be melted together to make glass, then chilling the mixed and combined ingredients. Without crystallizing, to harden. Specific properties of glass, such as colour, can be achieved using a special additive. There are many different bottles on the market, depending on the
chemical composition and use of additives, such as alkaline silicate glass, silica glass, borosilicate glass, barium glasses (T.V. screen), soda truss glass (window glass), glass Green, colourless, and brown are the most common hues for these glasses. [Viviana Letelier and Bastián I. Henríquez-Jara (2019)] [3]. Cement manufacturing is responsible for more than 8% of worldwide CO2 emissions. Approximately one ton of carbon dioxide is released into the environment for every ton of cement produced. Using discarded glass in concrete manufacturing saves resources, money and lowers greenhouse gas emissions [R.M. Andrew, 2018] [4]. Supplementary cementing ingredients such as silica fume, fly ash, and natural pozzolana have long been utilized as a partial replacement for cement in the concrete industry throughout the globe. Recently, researchers have attempted to replace cement in concrete with recycled resources such as recycled glass powder. [Al-jburi Najad A. A and Hasan Kareem (2019)] [1]. The particle size distribution of powdered glass is discovered to influence the pozzolanic characteristics of glass. When hydroxyl ions in the pore solution remove silicate ions from glass and combine them with calcium from portlandite, calcium silicate hydrate is produced. ASR expansion in concrete has also been demonstrated to be reduced by glass powder with a particle size of 300 m or less. [Abdul Ghayoor Khan and Bazid Khan (2017)] [5]. Calcium silicate hydrate (C-S-H) is formed by the unscratched reaction of pozzolanic with a low calcium silicate concentration when tiny glass particles are employed in concrete. It has been observed that when the particle size of glass powder decreases, the pozzolanic characteristics of the powder rise, resulting in a delayed increase in concrete strength. [N.A.Soliman, and A.Tagnit-Hamou(2016)] [6]. The characteristics of recycled glass, and therefore its impact on concrete, are determined by the glass type. The raw materials' chemical composition determines the nature of the glass reaction, which differs somewhat for each kind of glass. Furthermore, owing to the high lead concentration in the glass, the use of leaded glass in cement and concrete may cause lead leakage into the environment, resulting in severe contamination of soil and groundwater. Furthermore, the impact of varying degrees of cement substitution with recycled glass on the durability and strength of concrete must be assessed. [Nafisa Tamanna1 and Rabin Tuladhar (2020)] [7]. In contrast to manipulated samples, the compressive strength tests revealed that recycled glass concrete and mortar provided better durability. It was discovered that discarded glass might replace 20% of the cement, which would save costs while also being good for the environment. [Sadiqul Islam (2017)] [14].

2. MATERIALS

2.1. Cement
According to the study, the cement used was Ordinary Portland Cement. [Iraqi Specification No.5 - 2019] [8] as shown in tables (2-1) and (2-2).

Table (2-1) Chemical analysis of cement.

| Oxides           | percentage | Limitations of the Standard IQS\5\2019 |
|------------------|------------|----------------------------------------|
| Calcium Oxide CaO| 62.6       |                                        |
| silica oxide SiO2| 21         |                                        |
| Aluminum Oxide Al2O3 | 4.92    |                                        |
| Magnesium oxide MgO | 3.35    | 5 (max)                                |
| Iron Oxide Fe2O3  | 3.08       | -                                      |
### Table (2-2) Physical tests of cement.

| Characteristics                                      | Test results | Limitations of the Standard IQS / 5/2019 |
|------------------------------------------------------|--------------|------------------------------------------|
| fineness (m² / kg) by blaine method                  | 338          | 250                                      |
| Setting time                                         |              |                                          |
| Initial (minute)                                     | 1:45         | 45 minutes (min.)                        |
| Final (hour)                                         | 3:46         | 10 hours (max.)                         |
| Loading strength rate (Mpa)                          |              |                                          |
| 2 days                                               | 12.4         | 10 (min.)                                |
| 28 days                                              | 43.73        | 42.5 (min.)                              |

2.2. Glass powder

Clear waste glass powders (produced by ball mill) had a specific gravity and fineness that met the requirements. [ASTM C618 -2016][9]. As shown in table (2-3).
Table (2-3) Chemical Composition of Glass Powder

| Composition | Glass powder |
|-------------|--------------|
| SiO₂        | 70.02        |
| Na₂O        | 13.62        |
| CaO         | 9.95         |
| MgO         | 0.63         |
| Al₂O₃       | 2.18         |
| K₂O         | 0.15         |
| SO₃         | -            |
| Fe₂O₃       | 0.23         |
| TiO₂        | 0.11         |
| Cr₂O₃       | 0.02         |

2.3. Fine Aggregate (Sand)
The fine aggregate used for the study conformed to [Iraqi Standard No. 45 – 1984][10]. As shown in table (2-4) and (2-5)

Table (2-4) Sieve analysis of fine aggregate.

| Sieve size, (mm) | Cumulative percentage passing | Limits of Iraqi Standard IQS 45-1984, zone 2 |
|------------------|-------------------------------|---------------------------------------------|
| 10               | 100                           | 100                                         |
| 4.75             | 100                           | 90-100                                      |
| 2.36             | 81.7                          | 75-100                                      |
| 1.18             | 65.9                          | 55-90                                       |
| 0.6              | 50.8                          | 35-59                                       |
| 0.3              | 17.8                          | 8-30                                        |
| 0.15             | 4.37                          | 0-10                                        |

Table (2-5) Physical and chemical properties fine aggregate.

| Physical properties | Test result | Limits of Iraqi Standard |
|---------------------|-------------|---------------------------|
| Specific gravity    | 2.7         | -                         |
| Fineness modulus    | 2.86        | -                         |
2.4. *Quartz Powder*

The (CaO / SiO) mixture of the sheet determines the different combinations of (RPC) materials linked to dilute heat with more silica, which is essential. Quartz fine powder is blended in this manner with an average user amount of 10-15 m. The molecular range observed is 10 to 45 m, and the specific gravity is about 2.65.

2.5. *Silica Fume*

RPC material has a highly responsive silica pozzolan. Table (2-6) and (2-7) lists the additional characteristics of silica.

| Material property     | Result                      |
|-----------------------|-----------------------------|
| Particle size         | 0.55 μm to 1.1 μm           |
| Density               | 0.74 gm/cc                  |
| Moisture %            | 0.054%                      |
| Specific - Gravity    | 2.63                        |

*Table (2-6) The Physical Properties of Silica Fume.*

| Compounds             | ASTM C1240 | Results |
|-----------------------|-------------|---------|
| SiO₂ (min %)          | 85.00       | 90.90   |
| Moisture content (max %) | 3.00       | 2.90    |
| L.O.I (max %)         | 6.00        | 5.70    |

*Table (2-7) Chemical Requirements of silica Fume.*
2.6. Super Plasticizer

Selenium - 6100 is polycarboxylate material that has been processed and used as a superplasticizer. The properties of superplasticizers are illustrated in Table (2-8).

| Table (2-8) Super Plasticizer Properties. |
|------------------------------------------|
| Density                                  | 1.07 ± 0.01 at 250° C |
| P.H. Level                               | ≥ 6.00 at 250° C      |
| Content of chloride ion                  | < 0.2%                |

2.7 Steel Fibers

The steel fibre that used with diameter and length 0.5 mm and 30 mm. The mechanical properties related to steel filaments are shown below in Table (2-9).

| Table (2-9) Steel Fibers Properties. |
|--------------------------------------|
| Diameter(D)                          | 0.50mm                 |
| Length(L)                            | 30mm                   |
| Tensile strength(T.S.)               | >1450Mpa               |

2.8. Water

Mixing was done using spent water. The water used to treat the cubes in this study had a P.H (7.11).

3. EXPERIMENT PRESENTATION

Watertight and non-absorbent 10×10×10 cm³ cubes were used to make RRPC specimens according to British Standard. [BS 5328: Part 1, 1997]¹¹

The components were dry mixed for 4 minutes to produce the samples. The dry ingredients were then wet combined by adding 75% water and all superplasticizers to the mixture and mixing for another 8 minutes. The remaining water was then added, and the mixture was blended again until it was visually satisfactory. During the sample preparation, manual mixing was used.
After achieving a homogeneous mixture and layer-by-layer application to moulds, a steel pressure rod (16mm diameter) and (600mm length) with rounded ends was used to apply to press in two layers. The samples are kept in the moulds for one day to dry after the surface has been smoothed with steel floats. The samples were labelled without harming them once they were removed from the mould. Then, instead of high-temperature steam treatment in typical RPC, routine treatment of test materials up to the test for 28 days was conducted in water at 20 ± two °C.

4. TESTING
Before testing, any surplus moisture was removed from the specimen surface before being centrally put in the testing equipment. The mechanical characteristics of RRPC were next evaluated using British Standard Solid Concrete testing methods on three samples. [BS EN 12390-3, 2002][12]. At 7 and 28 days of age, the universal testing equipment was used to evaluate compressive strength and tensile split strength at a constant loading rate. The average readings and standard water treatment are given. Theoretical elasticity modulus = (3.65 √fc), where fc: is the compressive strength.

5. MIX PROPORTION
The water/binder ratio is 0.2. The ideal gauge for this steel filament is 2% based on volume around 155 kg m³. Fine aggregates were sieved using a 600µm standard sieve and utilized dry. Quartz powder is taken as a superplasticizer and filter inserted into a mixture supporting the benefit. The RPC Mix Proportion with Glass Powder shown in Table (5-1).

| Materials          | Mix-A       | Mix-B       | Mix-C       | Mix-D       |
|--------------------|-------------|-------------|-------------|-------------|
|                    | 100%Cem.    | 15%G        | 25% G       | 35% G       |
| Cement             | 750         | 637.5       | 562         | 487.5       |
| Silica fume        | 186.5       | 186.5       | 186.5       | 186.5       |
| Quartz powder      | 310         | 310         | 310         | 310         |
| sand               | 924.2       | 924.2       | 924.2       | 924.2       |
| Glass powder       | -           | 112.5       | 187.5       | 262.5       |
| SP                 | 11.24       | 11.24       | 11.24       | 11.24       |
| Steel Fibers       | 154.2       | 154.2       | 154.2       | 154.2       |
| Water              | 186.5       | 186.5       | 186.5       | 186.5       |
6. RESULTS AND DISCUSSION

To achieve a compressive quality of more than 125 N/mm², it's critical to create an optimal piece using locally accessible materials. The impact of two factors on compression quality, namely quartz powder rates, temperature range, and decreasing regulators, was examined in this manner. There are no particular mixing limitations; thus, any kind of sand or quartz powder may be used. The RPC material layout and mix settings are provided.

6.1. Compressive Strength

When glass powder is used, the average goal strength is met. When the glass powder content is increased, the quality suffers. The compressive strength increases with glass powder replacement up to 25% at a young age at 7 days, 25% glass powder replacement is 115 MPa. The minimum mean value is observed using 0% glass powder replacement. The highest pressure quality was seen in 28 days 35% to 25% powder glass was seen for the tests, pressure extension quality from 109 MPa to 133 MPa, as shown in fig. (6-1).

This improvement in compressive strength was also found by Aliabdo (2016)[13]. The compressive strength of the mortar was increased by about 9.0 per cent by using 10% glass powder. Additionally, employing 15% glass powder as a cement additive increased concrete compressive strength by an average of 16.0 per cent and produced better results than utilizing cement as a substitute.

![Compressive Strength](image_url)

**Figur (6-1)** Compressive Strength with versus Glass powder percentage

6.2. Modulus of Elasticity

Hypothetical elasticity study factor employing RPC with up to 35 % bond replacement of glass powder. The default elastic modulus is caused by the fluctuation (%) of the glass powder in Fig.(6-2). It has been
observed that it ranges from 35 GPa to 42 GPa for 15% to 25% glass powder. The default largest modulus of 42 GPa was chosen for 25% glass powder replacement.

![Modulus of Elastisity](image)

**Fig.(6-2)** modulus of elasticity with versus Glass powder percentage

### 6.3. Tensile Strength

Due to its fragility and unpredictability in resisting direct strain, concrete is fragile in tension. When subjected to tensile stresses, concrete fractures develop. To calculate the load at which concrete members may fracture, it is essential first to measure the tensile strength of the concrete. Split rigidity is obtained with Reactive powder concrete by using bond substitution of Glass powder (15%, 25%, and 35%); split rigidity varies from 7 MPa to 17 MPa, with a maximum tensile strength of 25% Glass Powder replacement after 28 days of curing as shown in figure (6-3). Tensile strength enables the material to sustain pre-cracking and post-cracking stresses without suffering brittle failure, which is typical in traditional concrete. [Kjellsen and Atlassi (1999)](ref).
7. CONCLUSION

Evaluation of mechanical characteristics of RPC using the waste of glass powder as a replacement for cement with silica fumes, superplastics, quartz powder, steel fibres, and sand was performed as part of a pilot study for environmental and economic reasons, among others. For this experiment, conventional treatment was used instead of steam treatment at higher temperatures. According to the results, the following analysis is a final conclusion. Reactive powder concrete with compressive strength above 130 MPa was generated using cement substitution for glass powder. High compressive strength of 133 MPa was achieved based on a mixture of 25% glass powder. A high splitting tensile strength of 17 MPa was obtained based on a mix of 25% glass powder. The high modulus of elasticity of 42 MPa was brought based on a mixture of glass powder of 25%. The glass powder 25% has the highest compressive strength, tensile strength, and modulus of elasticity. The water used to treat the cubes in this study had a P.H. value of 7.11.

For this research, the results of compressive strength, splitting tensile strength and modulus of elasticity tests with replacement rates of 25 per cent yielded the most incredible value, which was followed by replacement ratios of 35 per cent and 15 per cent, respectively, while the lowest value was without replacement at test ages of 7 and 28 days.

Fig. (6-3) tensile strength with versus Glass powder percentage
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