Influence of using different percentages of waste materials on the strength properties of polymer concrete

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ABSTRACT. Polymer concrete is a developed combined substance with greater characteristics in contrast with traditional concrete for example greater mechanical strength and chemical resistance. The aim of this paper is to investigate some properties of polymer concrete with and without waste glass as an aggregate. The waste glass was prepared and combined with different proportions of traditional sand. The mechanical properties (compressive strength, splitting tensile strength and flexural strength) were experimentally determined. The polymer concrete containing crushing waste glass was compared with polymer concrete containing normal fine aggregates. It was found that the waste glass could be used to produce polymer concrete and also is suitable for environment. This study concluded that 22% resin 78% fine aggregate of the total weight of mixture provides for the optimum distribution of fine aggregate, for that reason the best resin to fine aggregate ratio was chosen. The aggregate in polymer concrete was replaced with 5%, 10%, 15%, and 20% by weight of waste glass. It was also found that the compressive strength, flexural and tensile strengths of polymer concrete containing waste glass aggregate increases as the waste glass aggregate content increases.

KEYWORDS
Polymer concrete, epoxy resin, waste glass, binder.

Introduction

The main category of concrete consists of three components; cement, water and aggregate, which are mixed with various proportions depending on the desired properties [1]. Ordinary concrete is known to be weak in tensile strength, brittle and easily corroded by high-speed water stream and chemicals. It has become a growing problem in today’s society and the need for minimal maintenance and longer lasting construction. A different type of concrete was discovered by research in early 1950, polymer concrete [2] Polymer concrete (PC), as well as artificial resin and concrete are recognized as a coarse combined substance of fine sand, polymer binder and mineral filler, without cement [3]. It was reported to have been used in a range of civil and structural purposes for example: repair cracks in concrete, bridge decks, dangerous waste containers, decorative construction panels in addition to wastewater pipes [4]. With superior strength property, freeze-thaw resistance, fast setting time and capability to endure acidic environment [5]. Epoxy resin concrete is stronger as well as more durable than conventional concrete [6] it is the most important feature, mainly in structural uses. Practical study correlated to this type of concrete had commenced years ago [7, 8]. The quantity of binder material used is usually little and depend on the size of the filler. If a fine filler was used, more than 15% but no limit to 30 % binder can be required, but if it is usually 5 percent to 15 of binder is essential[3]. In order to improve the efficiency of polymer concrete it is necessary to use the least amount of bonding material and the best method of
Many studies used a little various ratio of aggregate plus resin. (Vipulanandan & Paul 1993) [8] the weight of aggregate was used 80% - 90% and the weight of binder was 10% - 20% while (Barbuta et al 2010)[9] used 12.7-18.7% of binder. The selection of epoxy resin is dependent on the price, availability and preferred properties. The most common kinds of resins are epoxy and polyester resin; this is because the elevated strength and resistance to chemical disintegration [2]. The research program aimed to investigate some mechanical properties of epoxy resin concrete further with and without waste glass as an aggregate.

**Materials**

### 2.1 Epoxy resin

Several types of available resin are found in companies and market. In this study, low viscosity epoxy injection resin system Nitofill EPLV was chosen. This resin is a base, which when hardened with suitable curing agents, has accepted adhesion strength, mechanical, insulation and chemical resistance features, table 1 illustrates the properties of epoxy resin. For curing this type, they should be mixed with a hardener.

**Table 1. properties of epoxy resin.**

| Property             | Typical results          |
|----------------------|--------------------------|
| Mixed Viscosity      | 100 mPa.s @35 °C         |
| Specific gravity     | 1.04                     |
| Gel time             | 90 minutes @ 20 °C       |
| 40 minutes @ 35 °C   |                          |

* Data sheet

### 2.2 Sand

Al-Ukhaider normal sand with maximum size 4.75 mm was utilized. The sand was dried in a furnace oven at 100 °C for twenty four hours before use in the mix. The gradation and properties of fine aggregate were within ASTM C33/C33M -13 as shown in table 2.

**Table 2. Fine aggregate properties.**

| Sieve size (mm) | Cumulative passing % | ASTM C33/C33M -13 |
|-----------------|-----------------------|--------------------|
| 4.75            | 100                   | 95-100             |
| 2.36            | 93.34                 | 80-100             |
| 1.18            | 80.34                 | 50-85              |
| 600             | 54.34                 | 25-60              |
| 300             | 17.74                 | 5-30               |
| 150             | 4.41                  | 0-10               |

Fineness modulus = 2.49  
Specific gravity = 2.63  
Sulfate content = 0.18%
Absorption = 1.65%

2.3 Waste glass
In this study, post-consumer domestic windows glass was used. First, the glass was washed well, dried and then ground to the size of sand with a hand-hammer crusher. The particle size distribution of waste glass was comparable to the particle size distribution of natural sand. Bulk density as well as specific gravity of waste glass are 1683 (kg/m³) and 2.58, respectively. Chemical composition of glass waste is shown in table 3.

Table 3. Chemical composition of waste glass.

| SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | K₂O | Na₂O | SO₃ | LOI |
|------|-------|-------|-----|-----|-----|------|-----|-----|
| 64.28| 3.12  | 1.62  | 13.11| 6.88| 0.59| 11.69| 0.23| 4.415|

Mix proportions
Design of mixtures step is unwell acknowledged for this type of concrete in the letters. Many researchers utilized different techniques to do so. Different studies took design of experimentations [9, 10] although other researchers choose design mixes arbitrarily [11] therefore, there is no common consensus between the research community for the steps of designing a mix of polymer concrete. The mixes of polymer concrete with addition of waste glass were documented from the situation of using the lowest amount of epoxy resin but enough for good workability.

Five mixes were prepared in the laboratory. The first mix is the control mix and the other four mixes were prepared to investigate the influence of addition of the waste glass on some mechanical properties of polymer concrete. Samples were selected utilizing the weight ratios of normal sand, resin and glass waste. For ideal PC1 sample had 73 % sand, 22 % epoxy resin, and 5 % waste glass.

Table 4 illustrates the mix proportion for all mixes.

Table (4) Mixing ratios for polymer concrete.

| Mixes   | Sand (gm) | Resin (gm) | Replacement ratio by weight of sand % | Waste glass (gm) |
|---------|-----------|------------|--------------------------------------|------------------|
| Control mix | 702   | 198        | 0                                    | 0                |
| PC 1    | 667      | 198        | 5                                    | 35.1             |
| PC 2    | 631.8    | 198        | 10                                   | 70.2             |
| PC 3    | 596.7    | 198        | 15                                   | 105.3            |
| PC 4    | 561.6    | 198        | 20                                   | 140.4            |

3.1 Mixing, casting and curing procedure
All mixes were mixed in accordance to ASTM C305-14 specification [13]. The compaction has been affected by means of a standard rod twenty-five blows/layer for three layers for 5cm cubes and 4×4×16 cm³ prisms. After 24 hours from casting, the specimens were demolded. The specimens were cured at room temperature 20 C°.
Test results and discussion

4.1 Compressive strength
Compressive strength was calculated by using cubical samples with 5 cm cube according to ASTM C109/C109M specification [14] using a digital compressive machine ELE international company with rate of load 15000 KN/min, the average of three samples were listed for each testing age. As expected, the replacement of the waste glass positively affected the compressive strength due to glass-aggregate particles being still relatively scattered and good ringed by polymer matrix. Aggregate glass may be a strengthening work on the closure of micro-cracks, which works on the development of compressive strength in the polymer mix [12]. This happening might be the reason of increased compressive strength of all mixes in reference to control mix. The results are shown in Fig.1.

![Figure 1. Compression strength chart](image)

4.2 Flexural strength
The flexural strength of PC was experienced by using third-point loading test method using prisms with (4×4×16) cm$^3$ in accordance with ASTM C348-18 specification [15]. The average of three samples was listed for each testing age. As expected, waste glass replacement positively affects the flexure strength. When looking at results of compression strength, it was found that replacing the waste glass in the mixture led to increase in the flexure strength of samples more when compared with the increased amount of the resin. This increase is directly proportional to the percentage of waste glass used in the mix. The results are shown in figure 2.

![Figure 2. Flexural strength chart](image)
4.3 Direct tensile strength
The direct tensile strength of PC was conducted on dog bone shape samples 76 mm length, 25mm thickness and 645 mm² cross section at mid-length. According to B.S 6319-7:1985[16] utilizing a testing machine of 10 kN capacity. The average of three samples was listed for each testing age. It has been observed that the glass particles of the matrix are high, and the particles that are placed vertically on the direction of the destructive force can be regulated by micro-reinforcement that was performed in increasing the tension strength of all mixes in reference to control mix [12]. The results are shown in the figure3.

![Figure 3. Direct tensile strength chart](image)

**Conclusions**
Depending on the outcomes of this investigation on PC, the following conclusions can be summarized:

1. The effect of use of waste glass on the strength of polymer concrete depends, on the percentage of waste glass used.
2. PC mixes designed with a combination of glass waste as a partial replacement of normal fine aggregate offered higher compressive strength, direct tensile strength and flexural strength than PC mixes with normal sand.
3. Recycling waste glass as fine material in polymer concrete manufacture may help in resolving environmental problem.
4. Exchanging natural fine aggregates with waste glass exhibits comparable results with respect to compressive flexural and direct tensile strength, however, further studies to survey the influences on durability and other characteristics are needful.

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