Some properties of green concrete with glass and plastic wastes

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Abstract. This study focusses on the flexural strength, flexural toughness, thermal conductivity, and failure modes under flexural for concrete containing 15% glass powder waste as partial replacement of cement by weight and 25, 50, 75, 100% plastic waste as volumetric replacement of natural coarse aggregate at 60 days.

The results show an increase in flexural strength and thermal conductivity when 15% glass powder waste was used, while there is a significant decrease with the use of plastic waste relative to reference specimens (without wastes). It can be observed a significant increase in total flexural energy when the content of plastic waste coarse aggregate is increased.

The incorporation of plastic waste aggregate in concrete with 15% glass powder changes the failure behavior of concrete specimens from a brittle to a more ductile failure. The failure in reference concrete specimens without coarse plastic waste aggregate occurs in matrix, through coarse aggregate, and around the aggregates in interfacial transition zone (ITZ). On the other hand, in concrete containing HDPE (high density polyethylene) plastic waste aggregate with 15% glass powder, the failure occurs mainly around plastic particles.

1. Introduction

Concrete is the basic material used to build cities and civilizations throughout the world. Every year the products of concrete all over the world are nearly (12000) million ton that expand about (1600) million ton of cement, (10000) million ton of aggregate and (1000) million ton of water[1]. Production of one quantity of cement generates nearly same quantity of CO₂ gas that causes ecological impurity. Thus, concrete manufacture considerably influences environment and health. Generally, it is not sensible to reduce the utilization of concrete but there are some ways to reduce its ambient affect[2].

Large amounts of various types of plastic and glass wastes are created all over the world. These wastes are entombed in landfalls. Since, the plastic and glass wastes do not degrade, so this method severely damages the environment.

Therefore, it is important to find new solutions for this problem. The best solution would be to Re-use, Re-cycle, and Reduce those wastes as much as possible [3].
Cement is a binder between the components of concrete, as well as the aggregate is considered as a large phase of concrete, which is about three-quarters of its size that leads to a large effect on the performance of concrete, such as: dimension stability and strengths, [4, 5]. With regard to sustainability, it is important to decrease the quantity of normal aggregate and cement that is used in concrete manufacture. Many researchers have made great attempts to exchange cement by alternate other materials. The use of supplementary cementations materials (silica fume, fly ash, and GGBS,... etc.) as substitute of cement are important[6]. Because the use of such materials leads to induce of green concrete. In Iraq the supplementary cementitious materials like, fly ash, and silica fume are not obtainable, also, metakaolin which need and exhausts a great quantity of energy through the process of burning, which makes it less environment friendly. So, it is important to invention alternate material, which can be used as a replacement to cement in concrete. The amount of glass wastes is constantly increasing in the world and particularly in Iraq due to the use of glass in daily life (windows, Pots,… etc.). Glass is a transparent material made from mixing at high temperatures of SiO₂, CaCO₃ and soda and then cooling them. It is a substance that does not degrade easily and needs thousands of years to degrade and thus, causes significant environmental problems [7]. Therefore, it should be disposed of in a way by its incorporation into the concrete.

Plastic materials are polymers made up of chains of organic nature. In according to physical characteristic, plastic can be classified into three categories, thermoplastic, elastomers, and thermostet, [8]. Globally the quantity of plastic materials has increased from 204 million ton in 2002 to 299 million ton in 2013[9], leading to a large quantity of waste plastic.

We can get rid of the wastes of plastic by either burring or burning, but both ways are unprofitable, in addition burning leads to environmental pollution. To decrease the issue of waste material, it is needed to utilize these wastes in an environmentally safe way, either in concrete industry by substituting reasonably to produce concrete with specific performance or as raw materials to make other products. Thermoplastic wastes with high density are used in this investigation that are found in most products such as greens containers, jugs, plastic bags, etc. High density polyethylene is categorized under poly-ethylene that has extended chains of carbon and hydrogen. Its chemical formula is \( \text{C}_n\text{H}_{2n} \). Generally, the polymerization of sample monomer of ethylene gives plastic [10]. The density according to American Society for Testing and Materials (ASTM D-3350) [11] ranges from 0.941 to 0.955 gm/cm³. The incorporation of plastic aggregate waste in concrete greatly improves some characteristics of green concrete, because these wastes have high toughness, low thermal conductivity coefficient, and low density [12]. Therefore, the novelty of this study is to use these wastes in concrete to improve some properties of concrete.

2. Experimental work
  2.1 Materials
Type (I) Portland cement was used in this study. Examination results show that the cement utilized is according to the Iraqi specification number (5) in 1984 [13]. Natural sand with 4.75mm maximum size and normal crushed coarse aggregate with maximum size (14) mm were used in this investigation. The results explain that SO₃ content, gradation and physical characteristics conform to the Iraqi specification number (45) in 1980 [14]. Tap water used in vital events was used for curing and mixing of concrete components.

High, range, water reducer, admixture(H RWR) with a trade tick of GLENIUM 54 was used. It agrees with American Society for Testing and Materials (ASTM)/ C494 type F. Plastic and glass wastes were utilized in this study after configuration and classifications [15].

2.2 Preparation of Wastes
Recycling of plastic and glass wastes namely, combination, washing, configuration, and classifying them was done according to the American Society for Testing and Materials (ASTM). Transparent glass waste was combined, washed, broken and then ground as shown in Figure (1).

![Figure 1](image1.png)  
**Figure 1.** Configuration of glass powder waste

Several experiments have been conducted on glass waste powder with fineness (7340 cm²/gm) to make its properties compatible with the properties of natural Pozzolan materials that are internationally known, which improves the properties of concrete according to American Society for Testing and Materials (ASTM C618) [16]. This investigation was done in previous studies of the same researchers and obtained a patent certificate under international number (C04B18/00). Also for plastic waste were combined from containers Vegetables after washing and cutting into small segments by crasher machine in Boob Al shaam area at south of Baghdad, then prepared and sieved on sieves to make grading of plastic waste correspond to Iraqi specifications number 45/1980 with maximum size of 12mm[14] and corresponding to normal aggregate used in this investigation. Figure (2) shows the prepared plastic waste gravel and normal crushed gravel.

![Figure 2](image2.png)  
**Figure 2.** Gravel used in this study

2.3 Experimental Tests
The next following tests have been conducted to know the influence of using more than one waste on some characteristics of green concrete:

- Thermal conductivity coefficient test by using cube samples with dimensions of (100*100*100) mm according to ASTM- C1113[17].
- Flexural strength test depending on American Society for Testing and Materials (ASTM-C78) [18] (by using 100×100×400 mm prism samples), during the test the load-deflection was measured using the linear displacement dial gauge connected to the computer in the middle of the sample.
- Total flexural energy test (using 100×100×400 mm prism specimens).
- Failure mode under flexural load.

2.4 Concrete mix design
Many trial mixes were carried out to choose the optimum percentage of glass wastes content, the results showed that the optimum percentage was 15.0% as a substitute by cement weight [15]. Table (1) gives the details of concrete mixes prepared in this investigation.

| Group | Concrete mixtures | Mix symbol | Glass powder waste content (%) | Plastic waste content (%) | Age (day) | Mix proportion by weight for reference mix (G0P0) |
|-------|-------------------|------------|-------------------------------|--------------------------|-----------|---------------------------------------|
| 1     | References        | G0P0       | 0                             | 0                        |           | 1:1.4:1.8                              |
|       | Concrete consist of 15% glass powder wastes as a substitute to cement | G15P0 | 15                             | 0                        |           | (cement: fine aggregate: coarse aggregate) with 500kg/m³ cement, w/c=0.27, admixture =1.5 Liter/100kg cement and slump 100±5mm |
| 2     | Concrete consist of 15.0% glass powder and various proportion of wastes of plastic as a volumetric substitute to normal gravel | G15P25 | 15                             | 25                       | 60        |                                        |
|       |                    | G15P50     | 15                             | 50                       |           |                                        |
| 3     |                    | G15P75     | 15                             | 75                       |           |                                        |
|       |                    | G15P100    | 15                             | 100                      |           |                                        |

3. Results and discussion
3.1 Flexural Strength
The flexural strength test results for all concrete samples are recorded in table (2), and figure (3). Generally, the highest increase was 34.7 % for concrete samples that contain 15.0% glass powder as a comparison with the reference mixes (do not contain wastes). This increment is caused because the glass powder improves the transition zone (ITZ) between cement paste and aggregate because of the pozzolanic reaction, in addition the filling capability of the voids between granules by additional gels, which is configured from this interaction, reduces concrete porosity that is inversely proportional to strength and thus, increases bending resistance [8]. The use of plastic wastes in concrete at specific proportions as compensation for natural coarse gravel in composite green concrete gives a significant decrease in bending resistance because of the reduction in the bonding force between the plastic wastes and cement paste. The proportion of reductions were 10.7%, 23.7%, 35.7%, and 46.3% for concrete samples with 25.0%, 50.0%, 75.0%, and 100.0% wastes of plastic on consecutive and compared with concrete samples with no wastes.
Figure 3. Flexural strength of concrete consisting of 15.0% glass powder and various contents of plastic aggregate wastes

3.2 Failure styles with Flexure Load

The form of failure for all concrete samples without plastic and also containing different percentages of wastes is shown in figure (4). For concrete containing only natural aggregate without wastes the shape of the failure was brittle and accompanied by a voice. In addition to separation of specimen into two halves, while the concrete samples containing different proportions of the plastic waste aggregate the form of failure was ductile and also had the ability to withstand the load of failure for a few minutes after failure without being separated. It can be seen that there is one crack in the samples of the test containing the wastes and its width increases with the increase of plastic content; this is because of the weak bond strength between the plastic aggregate waste and cement paste and the cracks appear around the plastic in the region ITZ.

Table 2. The influence of utilizing wastes of plastic aggregate and glass powder on characteristics of green concrete

| Plastic as a volumetric to natural aggregate with 15% glass powder as replacement with cement % | Flexural strength (N/mm²) | Total flexural energy (N.m) | Thermal conductivity (W/m.k) |
|---|---|---|---|
| G0P0 | 5.86 | 0.90 | 2.2994 |
| G15P0 | 7.65 | 0.95 | 2.3402 |
| G15P25 | 6.83 | 3.85 | 2.1699 |
| G15P50 | 5.84 | 8.12 | 1.6651 |
| G15P75 | 4.92 | 12.1 | 1.3029 |
| G15P100 | 4.11 | 15.55 | 1.0663 |
Form of failure of concrete samples containing different proportions of plastic waste.

1- with no plastic wastes  
2- 25% wastes of plastic  
3- 50% wastes of plastic

4- 75% Plastic waste  
5- 100% Plastic waste

**Figure 4.** Form of failure of concrete samples containing different proportions of plastic waste and 15% glass powder.

3.3 Total Flexural Energy

Flexure toughness or flexure energy is the area below the curve of the deflection-bending load curve [19] of the concrete samples with or without wastes, which are shown in figure (6), while the results of the test are shown in table (2) and figure (5). There is a significant increase in toughness by increasing the plastic wastes content of about 305.30%, 754.70%, 1173.70%, and 1536.8% for samples with 25.0%, 50.0%, 75.0%, and 100% plastic aggregate, respectively compared with samples with normal coarse aggregate. This increase is due to the possibility of absorbing the additional energy by the plastic waste aggregate resulting from bending load greater than the possibility of absorbing the additional energy by the natural coarse aggregate. This conclusion is agreed with the conclusion by Ismail and Al Hashmi [20].
Figure 5. The influence of various contents of plastic aggregate waste and 15.0% glass powder waste on total flexural energy of concrete.

Figure 6. Load to deflection curve for concrete samples with various plastic aggregate wastes and 15% glass powder waste.
3.4 Thermal Conductivity

The results of the thermal conductivity test for concrete samples with or without wastes are shown in table (2) and figure (7), which show a significant decrease in the thermal conductivity coefficient with an increase in the percentage of plastic wastes, the explanation are as below:

1- There are voids in the structure of plastic concrete, which increases the porosity and thus, reduce the coefficient of thermal conductivity compared to conventional concrete.

2- The presence of closed voids filled with air, which reduces thermal conductivity due to low thermal conductivity of air.

3- Thermal conductivity coefficient for plastic waste is very low (0.118 W/m.K) compared with normal coarse aggregate (2.0 W/m.K); these results are similar to those explained by Semiha et al. [21].

![Thermal Conductivity Diagram](image)

**Figure 7.** Influence of different percentages containing wastes of plastic aggregate and 15.0% glass powder on thermal conductivity of concrete.

4. Conclusions

From the results described in this study, the next, conclusions are possible as follows:

1. The use of plastic wastes as coarse aggregate in concrete gives considerable reduction in flexural strength. The ultimate reduction in flexural strength is 46.3% for samples containing 100.0% wastes of plastic as compensation for normal coarse aggregate.

2. The flexural toughness increases significantly with the increase of wastes of plastic. The percentage increase in flexural toughness is 305.30%, 754.70%, 1173.70%, and 1536.80% for samples with 25.0%, 50.0%, 75.0%, and 100.0% plastic aggregate as a volume compensation for natural coarse aggregates compared with samples with normal coarse aggregate.

3. There is a considerable reduction in results of thermal conductivity coefficient, when the content of plastic waste is increased.
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