Some properties of sustainable concrete with mixed plastic waste aggregate

W I Khalil and H M Mahdi1

1 Department of Building and Construction, University of Technology, Al Senaa Street, Iraq.

Email: kazazhala@yahoo.com

Abstract. The objective of this research is to study the influence of using waste material (irregular plastic mix) on and properties and behavior of concrete. Various coarse plastic aggregate of 15, 25 and 45 % as replacement to coarse natural aggregate by volume were carried out. The experimental program consists of many tests, compressive strength, splitting tensile strength, flexural strength, thermal conductivity, absorption of water and density. The results demonstrate that the increase of plastic waste content decreases the compressive strength; while the workability slightly improves. 

The dry density of the concrete decreases with the increase of the plastic waste aggregate, satisfied structural lightweight concrete can be produced with 45% replacement of plastic waste aggregate. Also, a major improvement in the thermal conductivity was observed, while the absorption of water growths as the plastic waste content increased.

1. Introduction

Waste is now a global problem, its solution must be considered by reducing the global generation of waste and aggrssing the energy challenges [1]. The improvement of manufacturing and urbanization all over the world caused large quantities of polymer waste materials [2]. The plastic waste material comes from surplus bottles, furniture made from plastic and equipment [1]. This waste causes huge problem in drainage system, wastage of resources and environmental pollution [1].

In this case focus is on the environment and safeguarding the natural sources through recycling of plastic waste by using it as construction material in the recent years[1]. Polymer aggregate is significantly lighter than natural aggregate and therefore, can be used to produce concrete with low density [1]. The goal of the research is to determine the influence of plastic waste inclusion on concrete properties.

2. Materials

2.1. Cement

The type of ordinary portland cement (I) used in this investigation is with the brand of (Al mass. The test results can show that the cement used is conforming to Iraqi standards 5/1984 [3].

2.2. Ordinary Fine Aggregate

Ordinary sand was carried from the Al_Ukhader area at a maximum element size of 4.75 mm. The analysis illustrate that it is identical with Iraqi Standard No. 45/1980 [4].

2.3. Normal Coarse Aggregate
Natural crumpled aggregate with particle size of 10 mm as maximum was cast-off. This aggregate was carried from al-Badra area. The results indicate that grading of particle size and sulphates meets the needs of Iraqi Standard No. 45/1980 [4].

2.4. Water
The water used to mix and treat concrete is drinkable water from the network water supply.

2.5. Admixtures (superplasticizer)
High range water reducing admixture (structure 520) used in this study is modified polycarboxylic ether, which has been primarily developed for applications where the strength, durability, and performance development are needed. It does not contain chlorides and match with ASTM C494[5].

2.6. Plastic Waste
Recycled mixed plastic waste was used from Bob Al Sham region (Its properties are listed in Table 1) with percentages of 15%, 25% and 45% as a substitution by volume of ordinary coarse aggregate. Plastic was splashed by water, and then broken to small particles. The plastic waste was graded using the standard sieves and prepared to conform to Iraqi Standard No. 45/1980 [6], which corresponds to the natural aggregates that are used to manufacture the concrete.

| Property                      | Tests results | Limit of Iraqi specification No. 45/1984 |
|-------------------------------|---------------|----------------------------------------|
| Absorption, (%)               | zero          | -                                      |
| Sulfate content (SO₃), (%)    | 0.03          | ≤ 0.1                                  |
| Density, (kg/m³)              | 949           | -                                      |
| Color                         | various colors| -                                      |

3. Experimental Works
3.1. Concrete Mixes
After selecting the optimal dose of HRWRA, several concrete mixtures were prepared. Table (2) shows the concrete mixtures prepared in this investigation.

| Mix symbol | Plastic waste | Admixtures HRWRA, (L/m³) | w/c ratio | Coarse aggregate (kg/m³) | Fine aggregate (kg/m³) | Cement, (kg/m³) |
|------------|---------------|---------------------------|-----------|--------------------------|------------------------|-----------------|
| Reference  |               |                           |           |                          |                        |                 |
| (A)        | 0             | 0                         | 0.42      | 0.3                      | 1146                   | 891             | 636.4           |
| (B)        | 15            | 62.12                     | 0.42      | 0.3                      | 994                    | 891             | 636.4           |
| (C)        | 25            | 103.4                     | 0.42      | 0.3                      | 877                    | 891             | 636.4           |
| (D)        | 45            | 186.7                     | 0.42      | 0.3                      | 643                    | 861             | 636.4           |

3.2. Casting and Curing
Molds were prepared, cleaned then their internal surfaces were oiled. The concrete mixture was prepared and casted in the molds with leveled surfaces. The molds were kept in laboratory conditions for 24 hours. After a day of casting process, the specimens were removed from the molds, and were immersed in water for curing periods of 7 and 28 days.

3.3. Experimental Tests

The following tests were done to investigate the properties of concrete:

3.3.1. Slump. After mixing all concrete mixtures were measured directly according to the test method of ASTM C143.

3.3.2. Compressive Strength. Three standard cubes of 100 mm³ are formed for each mix depending on BS 1881: part 116[7].

3.3.3. Splitting Tensile Strength. Cylinders of 100 mm diameter and 200 mm high were used in this test, which satisfy the requirements of ASTM C496 [8].

3.3.4. Flexural Strength. Prismatic samples (100 x 100 x 400 mm) were prepared and tested in accordance with ASTM C78[9]. The average value of two prisms for each mix was taken to calculate the flexural strength.

3.3.5. Thermal Conductivity. The main parameter that refers to thermal possessions of building materials is thermal conductivity for concrete. Two cubes were tested with dimensions of 100*100*100 mm in the National Center Laboratories conferring to ASTM C-1113[10]. The average of two values was calculated.

3.3.6. Dry Density test. Concrete oven dry density was premeditated conferring to ASTM C642 [11]. Cubic specimens having the dimensions of 100 mm were cast in this test. The age of this test was 28 days. Three samples were cast for each mixture and the average value was calculated.

3.3.7. Water Absorption test. This test was conducted as per ASTM C642 [11]. The samples that cast for this test were cubes with 100 mm. The average of three values of water absorption was calculated.

4. Results and discussion

4.1 Workability

The results were (95, 96.5, 98, 100) mm, respectively for mixes (A, B, C, D). The results confirmation was that concrete having plastic waste as coarse aggregate is more workable than normal concrete; it is attributed to the fact that this type of aggregate does not have the ability to absorb water compared with normal aggregate [12].

4.2. Compressive Strength

Compressive strength results for totally concrete specimens are shown in table (3) and figure (1). It is clear that the values decrease as the plastic waste material content increased. The drop percentages are 29.15, 33.8, and 49.4% for the concrete specimens having 15, 25, and 45% plastic materials, respectively in comparison to reference mix. The reduction in compressive strength for mixtures with plastic waste materials could be because of the bad bonding strength between cement paste and plastic aggregate [13]; this leads to weakness in interfacial transition zone, and the low strength of plastic aggregate. Generally it can be concluded that all concrete mixtures equipped in this study are structural concrete.
Table 3. Compressive, tensile and flexural strengths

| Test mixes | Compressive strength (MPa) | Tensile strength (MPa) | Flexural strength (MPa) |
|------------|-----------------------------|------------------------|------------------------|
|            | At 7 days | At 28 days | At 7 days | At 28 days | At 7 days | At 28 days |
| Ref. (A)   | 42.9     | 56.95     | 5.1       | 7.2       | 6.2       | 8.5       |
| B          | 35.1     | 40.35     | 3.15      | 5.9       | 4.8       | 7.2       |
| C          | 33.26    | 37.7      | 2.1       | 3.5       | 3.7       | 6.6       |
| D          | 25.4     | 28.75     | 1.1       | 2.1       | 2.2       | 5.8       |

4.3. Splitting Tensile Strength

The splitting tensile strength results of all concrete mixes are presented in Table (3) and Figure (2). As in the compressive strength results, the use of waste plastic aggregate decreases the tensile strength results of concrete by (181, 514, 70.3)% for concrete containing (15, 25, 45)% of plastic coarse aggregate, respectively. This reduction is due to the flat surface of the plastic coarse aggregate owing to a feeble connection between the plastic aggregate and cement pastes. Once concrete reaches the ultimate strength, the plastic aggregate does not fail but the failure occurs in the paste around plastic coarse aggregate [14].

Figure 1. Compressive strength results of concrete with various waste plastic aggregate contents.
4.4 Flexural Strength
Flexural strength test results of normal and sustainable concrete are exposed in table (3) and figure (3). These grades show that the flexural strength of sustainable concrete declines by the rise of plastic aggregate content percentage by (15.3, 22.4, 31.8) % for concrete containing (15, 25, 45) % plastic coarse aggregate, respectively. This is due to the weak bonding strength between cement paste and the surface of plastic aggregate [15].

4.5 Thermal Conductivity
The results of this test for reference and sustainable concrete are shown in table (4) and figure (4). It can be illustrated that the thermal conductivity decreases by growing the percentage of waste plastic aggregate in concrete by (14.6, 22.2, 26.5) % for concrete
containing (15, 25, 45) % plastic aggregate, respectively. This reduction is because of the drop in waste plastic aggregate thermal conductivity compared with normal aggregate [13].

![Figure 4](image-url)  
**Figure 4.** Concrete thermal conductivity results with various waste plastic aggregate contents.

4.6 Dry Density  
Dry density values are presented in table (4) and figure (5). It is clear that dry density of sustainable samples was lower than the reference concrete with percentage of (3.3, 6.7, 17.5) % for concrete having (15, 25 and 45) % plastic coarse aggregate respectively. These reduction caused by the lower density of waste plastic aggregate paralleled with normal coarse aggregate [13].

4.7 Water Absorption  
The results related to all concrete samples are represented in table (4) and figure (6). Concrete water absorption ratio increased with the increase of plastic coarse aggregate content. The reason is of pores creation in concrete microstructure which contain plastic waste aggregate and the angular shape of waste plastic aggregate, which indicates an increase in the adsorption of concrete as compared to normal concrete.

Commonly, the water absorption results for all concrete mixtures area lesser amount of than 10% by weight. That shows the decent feature of all concrete mixes containing plastic waste aggregate [16].
Figure 5. Dry density for concrete with different contents of waste plastic aggregate.

Figure 6. Water absorption for concrete with different contents of plastic waste aggregate.

Table 4. Results of test for thermal conductivity, water absorption and dry density

| Mixes | Tests | Thermal conductivity (W/m.K) | Water absorption (%) | Dry density (kg/m³) |
|-------|-------|------------------------------|----------------------|--------------------|
| Ref. (A) |       | 1.3029                       | 1.1                  | 2400               |
| B     |       | 1.1133                       | 2.8                  | 2320               |
| C     |       | 1.0135                       | 3.15                 | 2240               |
| D     |       | 0.9575                       | 4.2                  | 1980               |
5. Conclusions
   a) The workability of the concrete slightly increases when plastic waste aggregate content increases compared to that not containing plastic waste aggregate.
   b) The compressive strength of sustainable concrete is lower than that of normal concrete, but the sustainable concrete still classified as structural concrete, the rate of decrease in compressive strength were (29.15, 33.80, 49.42) % for the concrete samples having (15, 25, and 45)% plastic waste materials, respectively.
   c) The splitting tensile strength and flexural strength of normal concrete is higher than concrete containing plastic coarse aggregate.
   d) Concrete containing plastic coarse aggregate has thermal conductivity lower than that for normal concrete.
   e) The use of plastic coarse aggregate in concrete causes reduction in the dry density of concrete, concrete containing 45% as replacement of plastic waste aggregate by volume classified as structural lightweight concrete.
   f) The water absorption of concrete is increased when the normal coarse aggregate is replaced by plastic waste aggregate.

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