Behavior of Sustainable Reinforced Concrete Building Containing Waste Plastic and Fibers

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Abstract. Plenty of waste plastic is one of the major problems for environmental sustainability as plastic contaminates the mainland, rivers, and seas. Moreover, many-sided behavior of waste plastic (lightweight, flexible, cheap, strong, and moisture-resistant) can make it a replacement for or alternative to coarse aggregate in concrete. This paper investigates the properties and strength of reinforced concrete flat plate slabs using recycled waste plastic as a coarse aggregate instead of the conventional aggregate to produce lightweight concrete. Also studying the effectiveness of adding polypropylene fibers for enhancing both concrete properties and shear strength of the reinforced concrete respectively in a flat slab. All specimens had the same dimensions and main flexural reinforcement ratio and they were subjected to concentrated vertical loads. Four mixes had been tested in this work, the results showed that using waste plastic mixed with polypropylene fibers to produce lightweight concrete was very promising. It was observed that by adding polypropylene fibers the failure pattern was shifted from punching to flexural. Ultimate load, crack pattern, and deflection had been included and discussed for all specimens.

1. Introduction

As is known, the quantities of different waste materials are increasing day by day and the biggest problem is how to dispose of these materials. It is essential to know that plastic waste needs very long years to degrade naturally in the ecosystem and this makes it a chronic and accumulated problem, and the most important damage caused by this waste to the environment is the killing of many organisms, whether small or large, and the destruction of soil fertility and polluting sources Water with toxic elements contained in some plastic products. This is why we think about the appropriate use of these materials in the recycling industries. Several studies exist, but not enough to study the use of solid plastic waste in concrete production [1-5].

It is quite possible to utilize plastic waste in the production of lightweight concrete, there is little research in this area [6-8].

As it is known in concrete technology that lightweight aggregate concrete, LWAC, is not a new invention, as it has been known since ancient times. There are a large number of references regarding the use of LWAC [7].

Generally, concrete can be considered as lightweight concrete when it has a dry density of below than 2000 kg/m³. (LWC) can be manufactured in a number of ways, including replacing parts or whole ordinary aggregates with lightweight materials [7].
To improve the (LWC) properties, several techniques may be used, including the addition of polypropylene fibers with the use of plasticizers to give the required operability. As is known, polypropylene fibers have several advantages in thinness, large quantity, and non-aqueous absorption, and they do not react with any substances that can form stains, the cheapest type of fiber, has a strong resistance to acids and alkalies and also has a similar elastic modulus with concrete. Because of its smooth surface, it has excellent corrosion resistance [9].

2. Research significance
The environmental damage caused by the industrial waste, the preservation of depletion of natural resources, the need to generate and develop the methodological information and the urgent need to get rid of these wastes and recycling is one of the main reasons for this research, in addition to studying the effects of these wastes on the properties of the materials involved in construction works and its combined behavior. This research studies the properties and strength of concrete slabs using recycled plastic waste as an aggregate. This aggregate was used to replace the conventional aggregate to produce lightweight concrete. In addition, the efficiency of incorporating polypropylene fiber will be explored to enhance the properties of the reinforced concreted flat slab and its shear strength.

3. Experimental Work
3.1 Program of the work
The test specimens are divided into four groups according to materials that added to the concrete, as shown in Table 1. All the geometric slab specimens are similar and having the dimensions (450 ×450 ×50 mm) and loaded through a central column of dimensions (40×40 mm). All slabs have the same flexural reinforcement, and the dimensions are selected to fit the area label test machine dimensions. The slabs are reinforced in such a way so as to ensure a punching shear failure.

The boundary condition of test slabs is simply supported along all rims with a length from center to center of brace (420 mm).

| No. of group | Type of materials                          | symbol |
|-------------|-------------------------------------------|--------|
| 1           | Lightweight concrete contains waste plastic coarse aggregate only as a reference slab. | W      |
| 2           | Lightweight concrete contain waste plastic coarse aggregate + polypropylene fibers (0.6 %) from total volume. | WP     |
| 3           | Lightweight concrete contains waste plastic as a coarse aggregate + normal coarse aggregate. | WG     |
| 4           | Lightweight concrete contain waste plastic as coarse aggregate + normal coarse aggregate + waste plastic coarse aggregate + polypropylene fibers (0.6 %) from total volume. | WGP    |
3.2 Materials

3.2.1 Cement
From the Tasluja-Bazian factory, the ordinary portland cement used in this work. The chemical and physical characteristics of cement used were compatible on the Iraqi specification No. 5/1984 [10].

3.2.2 Fine Aggregate (Sand)
During the entire work, natural AL-Ukhaidher (4.75 mm) sand is used. Sand classification is in accordance with Iraqi Standard Specification No 45/1984[11 ], as shown in Table 2.

Table 2. Sieve analysis of fine aggregate.

| No. | Sieve size(mm) | (% passing) | IOS 45/1984 limitation for (Zone No.3 ) |
|-----|----------------|-------------|----------------------------------------|
| 1   | 10             | 100         | 100                                    |
| 2   | 4.75           | 98.86       | 90-100                                 |
| 3   | 2.36           | 96.53       | 85-100                                 |
| 4   | 1.180          | 90.28       | 75-100                                 |
| 5   | 0.60           | 64.21       | 60-79                                  |
| 6   | 0.30           | 14.65       | 12-40                                  |
| 7   | 0.15           | 2.17        | 0-10                                   |

3.2.3 Coarse Aggregate (Gravel)
From Al-Nibaey zone, the crushed gravel used in the current work. The utmost size of particle size was 10 mm, crushed gravel shall be washed away, deposited in the air for drying the layer, and placed in a saturated surface dry condition in the container before use. The gradients and the limit set by Iraqi Specification No. 45/1984[11 ] are shown in Table 3.

Table 3. Sieve analysis of coarse aggregate.

| No. | Sieve size (mm) | Cumulative passing % | Limit of Iraqi specification No. 45/1984 |
|-----|----------------|-----------------------|----------------------------------------|
| 1   | 14             | 100                   | 100                                    |
| 2   | 10             | 95.7                  | 85-100                                 |
| 3   | 5.0            | 18.63                 | 0-30                                   |
| 4   | 2.36           | 0.99                  | 0-10                                   |

3.2.4 Mixing Water
For casting and curing all the samples, drinkable water was used.

3.2.5 Polypropylene Fiber (PPF)
(PPF) with 19 mm long as shown in figure 1, has been used in this research. Table 4 indicates the physical properties of PPF used throughout this work.
Figure 1. Polypropylene fibers.

Table 4. Physical properties of PPF.

| Form                          | Virgin Polypropylene Fiber |
|-------------------------------|----------------------------|
| Specific gravity              | 0.91 g/cm³                 |
| Alkali content                | Nil                        |
| Sulfate content               | Nil                        |
| Chloride content              | Nil                        |
| Air entrainment              | Air content of concrete will not be significantly increased |
| Fiber thickness               | (18 and 30) μm             |
| Young modulus                 | (5500-7000) MPa            |
| Tensile strength              | 350 MPa                    |
| Melting point                 | 160 °C                     |
| Fiber length                  | 19 mm                      |

3.2.6 Source of recycled wastes

The sources of these waste materials are the industrial processes, which were collected from the factories for the production doors, windows and some of the home furniture, where these factories are widespread in the capital Baghdad, and then been cleaned and sieved to get rid of foreign objects and undesirable materials in the production of concrete. The shape of the plastic aggregate used in this study is irregular, not spherical, the grading of plastic waste aggregate is shown in Table 5.
Table 5. Grading of Waste Plastic aggregate.

| Sieve size | Cumulative % passing |
|------------|----------------------|
| 10 mm      | 86.4                 |
| 5 mm       | 12.3                 |
| 2.36 mm    | 1.3                  |

3.2.7 Glenium 51 (Superplasticizer)

Glenium 51 is one type of plasticizer characterized by being chloride free and complying with ASTM C 494 Types A and F specifications. moreover, it is consistent with all forms of Portland cement that meet with accepted international standards.

4. Molds

In order to prepare slab specimens, the concrete was poured into wood molds (450 × 450 ×50) mm.

5. Steel Reinforcement

Deformed wires used as flexural reinforcement with (Ø6 mm). The mean yield strength was 487 N/mm². Minimum steel ratio was (0.00769) depended on distributing the wires in two directions with spacing 105 mm center to center.

6. Mix Design

The control mix proportion for all groups are presented in Table 6 as shown below:-

| Group | Symbol | Cement content Kg/m³ | Sand Kg/m³ | Plastic Aggregate (kg/m³) | Gravel Kg/m³ | Water Kg/m³ | W/C ratio | PPF % | Sp. % | Density (kg/m³) |
|-------|--------|-----------------------|------------|---------------------------|--------------|-------------|-----------|-------|------|-----------------|
| 1     | W      | 450                   | 910        | 273                       | 0            | 139.5       | 0.31      | 0     | 1.5  | 1870            |
| 2     | WP     | 450                   | 910        | 273                       | 0            | 139.5       | 0.31      | 0.6   | 1.5  | 1865            |
| 3     | WG     | 450                   | 730        | 210                       | 450          | 139.5       | 0.31      | 0     | 1.5  | 1993            |
| 4     | WGP    | 450                   | 730        | 210                       | 450          | 139.5       | 0.31      | 0.6   | 1.5  | 1963            |

7. Testing program

In this research, the (150) mm cubic specimens were tested the compressive strength tests according to B.S 1881 [12] for all mixes. Figure 2 shows the details and dimensions of the test slabs.

8. Punching Test

The samples were removed from the treatment ponds and dried in the air for one day and then painted with a light white layer to show the fine cracks.

The location of the supports, central load, and dial gauge are indicated before the testing. A dial gauge of 0.01 mm tolerance tests the central deflector of the slab sample at the center of the plate. Figure 3 shows an illustrative testing method.
9. Design of Slab-column Connection

The model slab designed in this study consists of a square reinforced concrete slab of (450×450×50 mm). The load applied at the center of the plate by using a square steel column (40×40) mm. The ultimate design punching and the flexural load of test specimens are calculated according to ACI (318-11) [13]. The maximum flexural load for the test slab using the Yield-Line theory. The flexural strength predicted by yield-line;

\[ V_{\text{flex}} = 8m \left( \frac{1}{1-r} - 0.1716 \right) \]  
\[ m = \rho f_y d^2 \left( 1 - 0.59 \frac{\rho f_y}{f'_c} \right) \]

where:  
- \( m \) = unit moment capacity  
- \( r \) = column size dimension  
- \( L \) = specimen length  
- \( m = \rho f_y d^2 \left( 1 - 0.59 \frac{\rho f_y}{f'_c} \right) \)

where:  
- \( \rho \) = reinforcement ratio  
- \( f_y \) = yield strength  
- \( d \) = effective slab depth
f'c=concrete cylinder compressive strength
f'c= 0.8 fcu=0.8*22.2=17.76 Mpa
ρ= 0.00769
ρmax=0.01715 > ρ > ρmin=0.0018 O.K
m=0.00769×487×(35)^2\left\{1-0.59×0.00769×\frac{487}{22}\right\} =4126.9 N.mm/m
Vflex = 8 × 4126.9 × \left(\frac{1}{40} \times 10^{-3}\right) = 36.49 kN

ØVc = \frac{1}{3} \sqrt{f'c b o d}
Ø =0.85 for shear but it will not be used
bo= 4( r + d ) = 4 ( 40 + 35 ) = 300 mm
Vc = \frac{1}{3} \sqrt{17.76 \times 300 \times 35\times10^{-3}} = 14.75 kN
Punching failure is ensured.

10. Results And Discussion

10.1 Compressive Strength

The compressive strength of 30 days of age for several mixes was tested to determine strength development as a function of age as shown in Table 7 and figure 4.

**Table 7. Results of the compressive strength test.**

| Group | symbol | Average Cube Strength f\textsubscript{cu} (MPa) |
|-------|--------|---------------------------------------------|
| 1     | W      | 22.2                                        |
| 2     | WP     | 20.3                                        |
| 3     | WG     | 24.3                                        |
| 4     | WGP    | 22.6                                        |

**Figure 4. Specimens compressive strength.**
Using (PPF) in slab (WP) increasing the compressive strength ($f'c$) by about (9.6%) with respect to the reference slab (W), on another side, for slab (WG), by adding normal coarse aggregate the compressive strength ($f'c$) increased by about (11.5%) as compared with reference slab (W).

Also using (PPF) in the slab (WGP) increased the compressive strength ($f'c$) by about (19.5%) as compared with reference slab (W), the good effect has been recorded by adding (PPF) to mix contain both types of aggregate (waste plastic and normal) because the compressive strength ($f'c$) increased by about (7%) compared with slab (WG) who have the same mix proportion.

Adding (PPF) to slab (WGP) increased the compressive strength ($f'c$) by about (9%) as compared with slab (WP), in spite of the same ratio of (PPF).

Using this type of waste plastic aggregate enhanced the compressive strength of concrete ($f'c$) as compared with the research done by reference [8], who used different types of plastic Aggregate. this increase might be related to the decreasing (W/C) ratio by using superplasticizer, also the good interlock between the particles.

10.2 Crack Pattern and Load-deflection Relationship:
Four stages are distinguished on the typical load-deflection curves when a reinforced concrete flat plate or flat slab structure is subjected to gradually increasing loads:

The first stage (stage of elastic behavior) starts at the beginning of loading up to the first crack load.
The second stage (stage of cracking) starts at formation at first initial crack up to the first yielding; in this stage, flexural cracking of the slab develops. The third stage (stage of plastic behavior) starts after initiation of first yielding and up to the utmost flexural resistance, near that portend by the theory of yield line. In this stage (phase), yielding of the tension reinforcement diffused from the loaded zone toward the edge of the slab. Eventually, phase four (phase of fail) is the final stage for which there is no additional load at a plastic stage of rapidly increasing deflection, different observations of crack patterns are noticed according to the types of materials as shown in Table 8 below:

| Slabs type | First cracking load Pcr. kN | % Increasing in Pcr. with respect to (W) | Ultimate Load Pult kN | % Increasing in Pult. with respect to (W) | Deflection at ultimate load (mm) | % Increasing Deflection with respect to (W) | Density (kg/m$^3$) | Mode of failure |
|------------|-----------------------------|------------------------------------------|------------------------|------------------------------------------|----------------------------------|--------------------------------------------|------------------|----------------|
| W          | 7.5                         | ---                                      | 19                     | ---                                      | 5.6                              | ---                                        | 1870             | Punching       |
| WP         | 8                           | 6.7                                      | 21                     | 10.5                                     | 6.3                              | 12.5                                       | 1865             | Punching +Flexural |
| WG         | 8                           | 6.7                                      | 22                     | 15.8                                     | 7.1                              | 26.8                                       | 1993             | Punching       |
| WGP        | 9                           | 20                                      | 25.5                   | 34.2                                     | 8.3                              | 48.21                                      | 1983             | Flexural       |

On applying the load to the reinforced concrete slab specimens of this group, the first formed crack takes a circular path occurring under the loaded area at the tension surface of the slab. Cracking starts at a load of (39%) of the utmost failure load of slab (W) (reference slab) and about (38, 36 and 35%) for slabs ( WP, WG, and WGP) respectively. When the load increases after the forming of the first incision, more cracks begin to start and propagate toward the verge of the slab. When the concrete compressive strength is reduced, the cracks become finer and more in number, in slabs (W and WG) the cracks are wider than (WP and WGP) that contain fibers, as shown in figure 5 and figure 6.
The cracks continue propagating at the tension face of all slabs, while no cracks appear in the compression face except that observed around the loaded area at failure, the cracks then become wider with the increase in load until failure occurs. Figures 7, 8 and 9 shows that the load-deflection curve for groups (W and WP) respectively.

The slab behavior of group (WP) at failure shows more ductile than group (W). It is observed that the cracks are more in number and much finer in a slab of group (WP), as compared with group (W).

Figures 10 and 11, show the crack patterns for slabs (WG) of group 3 and (WGP) of group 4 respectively. Also, Figures 12, 13 and 14 show the load-deflection curves for (WG) and (WGP ) and comparison of the deflection between these slabs respectively.
The bond strength of polypropylene fiber with cement composite is the other key agent that influences the fiber-reinforced properties. (PPF) efficacy as a concrete reinforcement relies on fiber-matrix relations.

There is very weak chemical contact between (PPF) and the paste of cement. Besides, because of the easiness of releases after hardening, concrete types are often made from (PPF). Thanks to the abrasive nature of the aggregates, the containers of (PPF) in the concrete are divided into thousands of individual strands.

(PPF) fibers are disseminated everywhere in the entire matrix, giving a grate backup to concrete in every possible direction. This also describes the process by which the fibers are connected in the concrete to form interfaces with the cement matrix. Figure 15, shows the comparison of load-deflection curves between all groups.
The real benefit of the introduction of fiber is that fibers bind these cracks and succumb pull-out processes so that only the more energy source input will continue deformation. Fiber reinforcement extends under pressure more than concrete. Therefore, it is believed that the fiber-reinforced concrete composite system works as it wouldn’t have been strengthened until the “initial crack strength” is reached. Fiber reinforcement, therefore, takes over and holds the concrete together. With reinforcing, fibers pulling out of a composite monitor the total ultimate load-carrying capacity.

11. Conclusions
1. Using this type of plastic aggregate as waste material with mix proportion to produce lightweight concrete gives promising results.
2. Addition of (PPF) to specimens improves the ultimate load capacity at failure.
3. The punching shear in slabs without fibers is sudden, while it is gradual in slabs with fibers.
Figure 13. load-deflection curve of slab (WGP).

Figure 14. The comparison of load-deflection curves between slabs (WG) and (WGP).

Figure 15. The comparison of load-deflection curves between all slabs (W, WP, WG and WGP).
4. The deflection value for the slabs that contain the polypropylene fiber was larger than the control slab.
5. The obtained results of group WGP proved that the existence of (PPF) was influential in increasing the strength of punching shear.
6. The cracks in specimens containing (PPF) were very narrow and much in number than slabs without fibers.
7. The obtained results of group WGP proved that the existence of (PPF) was so effectual in increasing the strength of punching shear. Also, the failure pattern was shifted from punching to flexural.

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