Investigation the Properties of Waste Plastic Fiber Concrete Modified with HP-570 Super-Plasticizer

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Abstract. Recycling plastic waste has always been vital for sustainability, besides exploiting that waste to improve the mechanical properties of concrete mixtures which contribute effectively in the field of civil engineering applications. In this research, the enhancement of compressive, tensile and flexural strength of concrete mixtures was explored using both adding plastic fibers and HP-570 super-plasticizer. Plastic waste, as fibers, was mixed with an Ordinary Portland cement for a total volume of concrete of 0.5, 1, 1.5 and 2%, then the HP-570 super-plasticizer was added and the procedure was re-done. At the age of 28 days of curing, the compression strength was increased by (13.2%) while both tensile and flexural strengths were increased significantly by (117.4%) and (207.5%) respectively when using the plastic as fiber with 2%. Further improvement was gained by adding the HP-570 super-plasticizer for the concrete mixture.

Keywords: Plastic waste, Fiber reinforced concrete, concrete plasticizer, Concrete strength.

1.Introduction

In modern world, one of the most concern is how to get sustainability by recycling waste materials. Numerous waste materials are generated from manufacturing processes, service industries and municipal solid wastes (Siddique, Khatib, and Kaur 2008), Plastics have been used in many industrial and healthcare applications besides packaging, automotive, medical delivery systems, artificial implants, water desalination, land/soil conservation, flood prevention, preservation and distribution of food, housing, communication materials, security systems, and other uses. With these large and diverse applications, plastics contribute significantly to increasing solid waste volume (Subramanian 2000). The consumption of
various forms of plastics is a challenging environment protection issue, all forms of consumed plastic become waste and require large areas of land for storage (Sharma and Bansal 2016). The researchers must find solutions also original, imaginative and brilliant to the reuse of the waste. With the lack of spaces for landfilling and due to continuous increasing cost, the attention is towards the recycle of waste as an attentive to disposal. Research is always more interested in the use of such products in the concrete mix. This makes the concrete more economic and, at the same time, there is a reduction in the problem of waste (Foti 2013).

On the other hand, In recent years, an emerging technology named “Fiber-Reinforced Concrete (HPFRC)” has become popular in the construction industry. The materials used in FRC depend on the desired characteristics and the availability of suitable local economic alternative materials (Afroughsabet, Biolzi, and Ozbakkaloglu 2016). Fibers—in general—increase the compressive, tensile and flexural strength of concrete and it used in large varieties of constructions like highly loaded members, bridges, rigid pavement. Also, fiber concrete used in the footing and precast piles (Fam et al. 2003). Using fibers can make concrete resist to deformations without cracks or very fewer cracks compared with normal concrete (Muwashee, Al-Jameel, and Jabal 2018), also, adding waste plastic in reinforced concrete beams decreases the ultimate deflection at failure and increase the ductility behavior at the same time (Al-Hadithi, Abdulrahman, and Al-Rawi 2020). Furthermore, the waste plastic fiber concrete will be slightly lightweight (R. N. Nibudey; et al. 2013) and reduces 17.5% of concrete quantity and reduces 8.5% of the concrete cost (Singh and Kumar 2019).

One significant side effects of additions in concrete is the reduction in workability, the addition of waste plastics affects the free water available in concrete mixture and, consequently, the workability of the concrete (Sharma and Bansal 2016). The workability is inversely proportional to the ratio of waste addition and aspect ratio (Khatab, Mohammed, and Hameed 2019). For example, it decreases when the addition of waste plastics increases by up to 25% (Bhogayata and Arora 2017). As a result, using concrete plasticizer will be vital to improve the workability when the plastic additions were used.

This research aims to investigate the variation of some mechanical properties in concrete when using plastic fibers made from waste bottles and produce low-cost mixtures at the same time, then using both HP-570 super-plasticizer with plastic fibers. Using the plastic fiber as strips has not been covered adequately besides using the HP-570 super-plasticizer to overcome the decrease in the concrete workability.

2.Experimental Work

2.1 Materials used in the study:

330 kg/m³ of ordinary Portland cement was added to normal fine and coarse aggregate to produce a conventional concrete using drinkable water, the amounts of all other mix components were listed in table 1. All in-use material was tested to make sure that the concrete mix meets the Iraqi standard specifications. The grain-size distribution curves for the aggregates were shown in tables 2 and 3 and figure 1 which already meet Iraqi Standard - 45 (Specification 1884). The physical and chemical tests of Portland cement were shown in table 4 which already meet Iraqi Standard – 5 (Specification 1984).

Plastic fibers used in this study were obtained by slicing off used plastic bottles of water which are widely available in local markets. Along with using plastic fibers, HP-570 super-plasticizer was also used as an
additive for the concrete mixture to enhance its compression, tensile and flexural strengths, the essential related properties of plastic and the admixtures were listed in tables 5 and 6.

2.2 Specimens and testing procedure:

Three types of specimens were used to determine the mechanical properties of the newly tested concrete as explained in table 7. While the compression test was gained by direct test, the tensile strength was gain from the approximate method of splitting test. Moreover, the flexural strength was calculated according to British standards B.S 1881(Standard 1881) using the following formula:

$$\sigma_{flex} = \frac{F \cdot L}{b \cdot d^2}$$  (1)

where:

\(\sigma_{flex}\): the flexural strength of concrete beam (modulus of rupture) due to bending stress.

F: the maximum load applied by the machine.

L: the distance between supports.

b: the width of the beam, and

d: the depth of the beam

All concrete members were categorized in three major groups, the first is the reference group (I) which means neither plastic fibers nor admixture is being used, the concrete with the plastic fiber was the second group(II), eventually, the final group (III) was the concrete specimens when using the plastic fiber coupled with the HP-570 super-plasticizer as shown in figure 2.

Each test was performed for three specimens to adopt the average value of each case. All specimens were tested after 28 days of curing by putting them in water as shown in figures 3 and 4.

Table 1. Mix proportion used in the study (for each 1m³ of concrete)

| Reference Mix. | Cement | Sand | Gravel | Water | HP-570 super-plasticizer | w/c |
|----------------|--------|------|--------|-------|--------------------------|-----|
| kg for each 1 cubic meter | 330 | 620 | 1200 | 160 | 1.2 liter per 100 kg cement | 0.3 for mixes with HP-super-plasticizer |

Table 2. Grading of coarse aggregates used in the study

| Sieve size | Percentage of passing (%) | IQS-85, limitations for coarse aggregate (%) |
|------------|---------------------------|--------------------------------------------|
| 40 mm      | 100                       | 100                                        |
| 20 mm      | 96.2                      | 95-100                                     |
| 10 mm      | 43.8                      | 30-60                                      |
| 4.75 mm    | 1.9                       | 0-10                                       |
Table 3. Grading of fine aggregates used in the study

| Sieve Designation | Percentage passing (%) | IQS -85, limitations for zone 1 fine aggregate (%) |
|-------------------|------------------------|-----------------------------------------------|
| 10 mm             | 100                    | 100                                           |
| 4.75 mm           | 93.6                   | 90 - 100                                      |
| 2.36 mm           | 80.1                   | 60- 95                                        |
| 1.18 mm           | 68.8                   | 30-70                                         |
| 600 mic           | 37.3                   | 15-34                                         |
| 300 mic           | 10.1                   | 5-20                                          |
| 150 mic           | 3.9                    | 0-10                                          |

Figure 1. Grain size distribution of fine and course aggregate
Table 4. The physical and chemical tests of Portland cement

| Groups   | Test                                      | Test results | Iraqi specification No5/1984 |
|----------|-------------------------------------------|--------------|-----------------------------|
| Physical tests | Fineness, Blaine method (m²/kg)          | 306          | >250                        |
|          | Initial setting time (hour:min)          | 1:37         | >0:45                       |
|          | Initial setting time (hour:min)          | 5:10         | <10:00                      |
|          | Compressive strength (MPa) 3 days        | 16.6         | >15                         |
|          |                                            | 24.9         | >23                         |
|          | Compressive strength (MPa) 7 days        |              |                             |
| Chemical tests | CaO%                                      | 61.76        | ----                        |
|          | Silicon Dioxide (SiO₂)%                  | 20.6         | ----                        |
|          | Aluminum Oxide (Al₂O₃)%                  | 3.50         | ----                        |
|          | Iron Oxide (Fe₂O₃)%                      | 4.72         | ----                        |
|          | Lime Saturation Factor (LSF)             | 0.9          | 0.66-1.02                   |
|          | Magnesium Oxide (MgO)%                   | 2.22         | <5%                         |
|          | Tricalcium Aluminates (C₃A)%             | 0.38         | <3.5%                       |
|          | Sulfur Trioxide (SO₃)%                   | 2.07         | ≤ 2.5 if C₃A less than 5%   |
|          |                                            |              | ≤ 2.8 if C₃A more than 5%  |
|          | Loss in Ignition (LOI)%                  | 1.26         | <4%                         |
|          | Insoluble Residue (IR)%                  | 1.12         | <1.5%                       |

Table 5. Properties of the plastic water bottles

| Plastic fiber from water bottles | Chemical composition | Tensile strength | density | Melting point | Approximate Dimensions | Aspect ratio |
|---------------------------------|----------------------|------------------|---------|---------------|------------------------|--------------|
| DATA [C₂H₄]ₙ chains            | 48 - 72 MPa          | 0.88 – 0.96 gr/cm³ | 115 – 135 centigrade | 0.5 x 1.5 cm          | 75          |

Table 6. HP-570 super-plasticizer admixture properties

| HP-570super-plasticizer type | Color       | Specific Gravity | Dosage         | Chloride content |
|------------------------------|-------------|------------------|----------------|-----------------|
| Liquid super-plasticizer     | light brown | 1.1              | 500-220 ml for 100 kg cement | NIL       |

Table 7. Types of concrete specimens with its related test

| Specimen shape | Dimensions (mm) | Related Mechanical Property | Type of Test                  |
|----------------|-----------------|----------------------------|-------------------------------|
| Cubes          | 100 x 100 x 100 | Compressive strength       | Direct Test                   |
| Cylinders      | 100 x 200       | Tensile strength           | The approximate method of splitting test |
| Prism          | 100 x 100 x 400 | Flexural strength          | Third point loading           |
Figure 2. Plastic fibers (Mixed with concrete) used in the study

Figure 3. Compression, splitting tensile strength testing for member used in the study
3. Results and Discussion

The results of compression strength, splitting tensile strength and flexural strength for all types of concrete members were summarized in table 8, the first group of specimens was tested with 0% plastic fiber with no admixture also in order to be reference values for comparing other results with.

The plastic fibers were added gradually starting from 0.5, 1, 1.5 reaching up to 2% without any use of admixtures for the second group, then the procedure was repeated for the third group by adding the HP-570 super-plasticizer, these samples were tested to find the combined effect of adding plastic fibers together with admixture.

The compressive, tensile and flexural strengths were increased ultimately by 13.2%, 117.4% and 207.5% respectively when comparing the results of the second group with the reference one. The significant increase in strengths -especially in tensile and flexural- may be attributed to two major reasons; this first one is that the existence of plastic fibers in concrete will reduce the propagation of cracks under loaded specimens, this reduction gives more time of receiving loads which will increase the strengths. The second reason backs to the properties of the plastic fibers itself, which has high tensile strength as mentioned in table 5.

Additional enhancement was recorded in all previously mentioned properties when adding the HP-570 super-plasticizer for the last group of concrete, the increase of the values was rising by 14.6%, 151.7% and 369.8% respectively. This behavior was illustrated in figures 5, 6 and 7.

Figure 4. Flexural strength testing for member used in the study
Table 8. Tests results

| Groups | Mix Type                                                  | Compressive Strength (MPa) | Tensile Strength (MPa) | Flexural Strength (MPa) |
|--------|-----------------------------------------------------------|----------------------------|------------------------|-------------------------|
| I      | Reference Mix: 0% Plastic Fiber with No HP-570 super-plasticizer | 25.43                      | 1.72                   | 2.25                    |
| II     | 0.5% Plastic Fiber with No HP-570 super-plasticizer      | 26.15                      | 2.80                   | 3.86                    |
|        | 1% Plastic Fiber with No HP-570 super-plasticizer        | 27.40                      | 3.54                   | 6.24                    |
|        | 1.5% Plastic Fiber with No HP-570 super-plasticizer      | 28.43                      | 3.70                   | 6.87                    |
|        | 2% Plastic Fiber with No HP-570 super-plasticizer        | 28.80                      | 3.74                   | 6.92                    |
| III    | 0.5% Plastic Fiber with HP-570 super-plasticizer         | 26.73                      | 2.97                   | 5.12                    |
|        | 1% Plastic Fiber with HP-570 super-plasticizer           | 27.95                      | 3.88                   | 7.45                    |
|        | 1.5% Plastic Fiber with HP-570 super-plasticizer         | 28.70                      | 4.17                   | 8.76                    |
|        | 2% Plastic Fiber with HP-570 super-plasticizer           | 29.14                      | 4.33                   | 10.56                   |

Figure 5. Increasing percentage in compressive strength
Figure 6. Increasing percentage in tensile strength

Figure 7. Increasing percentage in flexural strength
From figures 8 and 9 it can be seen that high increment of increase in tensile and flexural strength by using plastic fibers only, this increase could be attributed to the action of fibers which arrest the propagation of cracks under loading before failure (R. N. Nibudey; et al. 2013). This action gives long time to hold loads before failure, as a result, higher tensile and flexural strength. Moreover, fibers (in general) support concrete (which is already a brittle material) to resist cracks generation under loading (Mahadik, Kamane, and Lande 2014). The second reason is due to the high tensile strength of plastic fiber itself as mentioned in table 5. Compressive strength slightly increased by adding plastic fibers, as shown in figure 8. This is agree with the results of some studies such as Ramadevi and Manju (2012), Maqbool et al. (2019) and Prahallada and Prakash (2013).

By using both HP-570 super-plasticizer and fibers as shown in figure 8, the tensile and flexural strength increased significantly, that could be explained by the action of HP-570 super-plasticizer which reduce w/c ratio used in concrete and give higher strength comparing with ordinary concrete that have no super-plasticizer admixture (Salem, Alsadey, and Johari 2016).

Unlike the behavior of normal concrete during failure which happens all in a sudden, the concrete with fibers was taken longer time before complete the failure, this case was observed especially when testing the prism, this different behavior indicates that the ductility of concrete was increased by adding plastic to it as can be seen from figure 4.

![Figure 8. Increasing percentage in strengths as a result of adding plastic fiber only](image_url)
4. Conclusions

- Using waste plastic as fibers improve the mechanical properties of concrete such as compressive, tensile and flexural strength.
- A small increase in strength noticed when the percentage of plastic fibers exceeds 1.5%.
- The combination effect of the plastic fiber and HP-570 super-plasticizer produce a significant increase in flexural strength.
- Reinforcing concrete by plastic fibers give ductile failure in flexure test comparing with ordinary concrete.

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