Mechanical Properties of Concrete Contain Waste Fibers of Plastic Straps

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Abstract. This study examined the utilization of polyethylene terephthalate (PET) strap waste as fibers to reinforce the concrete. The fibers were obtained by simply cutting the strap. An investigation was carried out on 7 batches containing PET waste fibers as a volumetric fraction of concrete. The parameters were the fibers fraction ratio ranging from (0-0.5) % and aspect ratio (2.5 and 3). Compressive strength, slump test, and splitting tensile strength were the test supplied to concrete. The test results indicate that the PET fibers improve the splitting tensile strength and slightly decrease the compressive strength and workability. So that, the concrete produced can be used in paving, industrial flooring, precast concrete, and shotcrete. Furthermore, a way to reuse plastic waste will be utilized to contribute to saving the environment.

1. Introduction
Since ancient times, the idea of adding one substance to another has been applied to improve the property or properties of one of these materials. Straw and horse hair have been added to clay to improve the characteristics of the bricks. Today, fibers are used in various forms to enhance the concrete.
Normal concrete is characterized by its relatively high compressive strength on the one hand, and on the other hand, it has low tensile strength, limited flexural strength and low resistance to the formation and expansion of cracks that appear even before the load is applied as a result of volumetric changes resulting from shrinkage or temperature change. Therefore, many researchers have concluded that the addition of fiber to the normal concrete leads to confrontation these problems and improve the properties of concrete [1][2][3]. There are many types of fibers that are added to concrete, such as iron fibers, synthetic fibers, fiberglass, natural fibers, iron fibers are the most common type. The addition of fiber to concrete is used in various applications such as industrial flooring, concrete paving, precast concrete, shotcrete, and many other applications.[1]
The size of the fiber sample is one of the most influential variables on the properties of fibrous concrete. There are also many characteristics such as the surface area of the fiber, the distance between the fiber and the aspect ratio (the ratio of the length of fiber to diameter).
Plastic, one of the most important discovery of the 20th century, have become an unavoidable part of our lives. A notable increase in the using of plastic annually has been rising steadily. It is used in various applications namely automotive, agriculture, electronics and electrical commodity, packaging, and other uses [4][5][6][7].
In general, Plastics can be categorized into two groups, thermosetting plastic, and thermoplastic. Thermosetting plastics are known as silicone, melamine, phenolic, epoxy resin, unsaturated polyester, and polyurethane, cannot be melted by heating. Otherwise, thermoplastics can melt and harden with heat and cooling, such as polyethylene (PE), polystyrene (PS), polypropylene (PP), polyethylene terephthalate (PET), and high-density polyethylene (HDPE) [8][9].
Because of the plastics benefits, such as lower-cost and suitability of utilizing, a significant demand is ever increasing all over the world. As a result, About 7 billion tons of trash were produced from 2015 until 2017 [10], [11]. Only 9% have been recycled and 12% have been burned while 79% have been accumulated in a landfill or natural environment. Pollution by plastic is one of the most dangerous types of pollution harmful to both the environment and human beings. The non-degradation of plastics means the accumulation and damage to many organisms. Among the plastic wastes, PET is the most common. It is gained in large quantity from containers for liquids and foods, strap for long-term storage and/or transport, etc. So, it is important to reducing and/or re-utilizing PET waste in varied applications.

A different application of plastic waste in concrete have been examined, thus achieve to reusing the waste materials and provide alternative sources of sand in novel concrete mixes. Research has been carried out for utilizing recycled PET as an aggregate in concrete by N. Saikia and J. de Brito[12], who explored the effect of different sized and shaped of PET particles on the fresh and hardened properties of concrete. Three different ratios of natural aggregate replacement, ranging from 5% to 15%, for each shape and size of PET aggregate were tested. It was found that the Compressive strength is inversely proportional to increased replacement ratio. This lack attributed to the lack of interaction between the PET particles and cement mortar.

The effecting of contents and sizes of plastic wastes on the fresh properties and compressive strength of self-compacting concrete were investigated by Hama and Hilal[13]. Three various sized of plastic wastes with six different contents were used as a partial replacement by volume of natural sand. The tests results showed that with the increase in the size and content of the plastic waste parts lead to a decrease in workability properties and compressive strength, but remains possible for use as a fine aggregate in self-compacting concrete.

Islam et. al. [14] reached the same results but using another type of PET as coarse aggregate. PET aggregate was resulted after shredded the used PET bottles into flakes and melted using the oven and then cooled. The Aggregate with a relatively smooth surface and has a rounded shape. Five of replacement ratios ranges from 0% to 50% with three different water-cement (w/c) ratios (0.42, 0.48 and 0.57) were selected to investigate fresh and hardened properties of concrete with PET aggregates. Nibudey et al.[15] added plastic fibers to the concrete at 0% to 3% of the weight of the cement with aspect ratios of 35 and 50 to study the effects of plastic fibers on the properties of concrete. Test results show that the dry density, compressive strength, and workability decreased with increasing aspect ratios and fiber content.

Oliveira and Castro-gomes [16] investigated the using of (PET) bottle fiber recycled as fiber reinforced renders mortar. Different volumes of fibres, i.e. 0%, 0.5%, 1.0% and 1.5%, were introduced in dry mortar mixes. The results indicate that the incorporation of PET fibers significantly improves the flexural strength of mortars with a major improvement in mortar toughness. This research will study the physical and mechanical properties of concrete with PET strips; to our knowledge, no study has been done on the properties of PET strips as fiber in concrete. Therefore, the novelty of this study is to provide data to help fill this gap by using a new type of plastic waste in the concrete. For this purpose, two different aspect ratios (2.5 and 3) and three volumetric additions ratio (0.1, 0.25 and 0.5 %) of fiber will be used to obtain compressive and splitting tensile strength and workability of concrete.

2. Experimental program and tests

2.1 Materials and mix proportions

2.1.1 Concrete mixture

Portland Limestone Cement (CEM II/A-L 42.5R) produced by the Lafarge cement company from Iraq having properties shown in Table 1 was used. The results showed that this type is identical to the Iraqi standard specifications (IQS No.5/1984) [17]. Coarse aggregates with 12.5 mm maximum size which are locally available around Samarra city were. Tigris river sand was used as fine aggregates after sieving on a sieve size 4.75 mm. Coarse and fine aggregates had 2.71 and 2.63 specific gravity with
0.5% and 1.78% water absorption, respectively. Table 2 and 3 and Figure 1 and 2 show the results of sieve analysis for coarse and fine aggregate, respectively, and comparison it with Iraqi specifications IQS No.45/1984[18].

### Table 1. Chemical and physical properties of cement

| Oxides composition | Content % | Limit of Iraqi specifications IQS No.5/1984 |
|--------------------|-----------|---------------------------------------------|
| Al₂O₃               | 4.65      | 6.2 - 6.5                                   |
| SiO₂                | 20.1      | 20.7 - 21.5                                 |
| Fe₂O₃               | 3.42      | 2.54 - 2.64                                 |
| CaO                 | 60.45     | 62.0 - 65.0                                 |
| SO₃                 | 2.13      | Max. (2.8%)                                 |
| MgO                 | 3.9       | Max. (5%)                                   |

| Physical properties | Test results | Limit of Iraqi specifications IQS No.5/1984 |
|---------------------|--------------|---------------------------------------------|
| Setting time (vacat apparatus), min | | Not less than 45 min. Not more than 10 hrs |
| Initial             | 130          |                                             |
| Final               | 245          |                                             |
| Compressive strength (MPa) | | Not less than 15 MPa Not less than 23 MPa |
| At 3 days           | 29.1         |                                             |
| 7 days              | 33.7         |                                             |

### Table 2. Sieve analysis for coarse aggregate

| Sieve size (mm) | Cumulative passing % | Limit of IQS No.45/1984 |
|-----------------|-----------------------|-------------------------|
| 12.5            | 93.98                 | 90-100                  |
| 9.5             | 85.46                 | 85-100                  |
| 4.75            | 16.7                  | 10-30                   |
| 2.36            | 0.164                 | 0-10                    |

### Table 3. Sieve analysis for fine aggregate

| Sieve size (mm) | Cumulative passing % | Limit of IQS No.45/1984, zone no.3 |
|-----------------|-----------------------|------------------------------------|
| 4.75            | 94.4                  | 90-100                             |
| 2.36            | 91.35                 | 85-100                             |
2.1.2 Strap plastic waste (SPW) fibers

Plastic straps that use to fasten and hold effectively boxes, closing shipping containers and papers, made from polyethylene terephthalate (PET) were cut into fibers with 2.5 and 3 aspect ratio, as shown in Figure 3. Varying fractions of fibers from 0% to 0.5% by volume of concrete were mixed. Concrete with 0% of SPW was deemed as reference concrete.
2.2 Mixture proportions and specimens

Seven mixtures were mixed and cast. Mix proportions and the details of the mixtures are illustrated in Tables 4 and 5. Before water addition, all of the components had been mixed in dry conditions until the SPW homogenization in the mix after few initial rotations of the mixer. To obtain compressive strength for each mixture, three (150 mm * 150 mm * 150 mm) cubes were prepared and tested. Also, three cylinders (150 mm * 300 mm) were cast in order to split tensile strength test. The effect of the SPW addition of the fresh concrete was investigated by the slump tests. Total 42 specimens were prepared, including 21 cubes and 21 cylinders. Basic methods for the preparation of materials and the batching, mixing and sampling of fresh concrete in the laboratory and curing of the test samples complied with (BS 1881: Part 125:1986) and (BS1881:Part111:1983) [19][20]

Table 4. Mix proportions of concrete

| W/C ratio | Water (kg) | Cement (kg) | Fine agg. (kg) | Coarse agg. (kg) |
|-----------|------------|-------------|----------------|-----------------|
| 0.6       | 210        | 350         | 700            | 1400            |

Table 5. Batch details of concrete mixes.

| Batch | PET waste fraction | Aspect ratio |
|-------|--------------------|--------------|
| B1    | 0%                 | 0            |
| B2    | 0.1%               | 2.5          |
| B3    | 0.25%              | 2.5          |
| B4    | 0.5%               | 2.5          |
| B5    | 0.1%               | 3            |
| B6    | 0.25%              | 3            |
| B7    | 0.5%               | 3            |

2.3 Workability tests on fresh concrete

The homogeneity of the concrete mixes and its workability were examined by the slump test as shown in Figure 4. The British Standard (B.S 1881: Part 102:1983)[21] was adopted in the test procedure. Slump values for concrete mixtures are shown in Table 6.
2.4 Tests on hardened concrete

2.4.1 Compressive strength test
The compressive strength of the cubes was examined according to the British standard (B.S 1881:Part116:1983)[22]. Compression load was subjected to the cube specimens by using a universal machine of 1000 kN loading capacity with a constant rate of loading till the specimen failure. The tests were executed at age 7 days. By dividing the failure load on the cross-sectional area of a cube, the compressive strength was obtained as stress causing the failure and showing the significant fracture in a specimen.

2.4.2 Splitting tensile strength
The indirect tensile strength of concrete was measured by splitting tensile strength. The axial compression load was subjected by using a universal machine of 1000 kN loading capacity along the length of the cylinder specimens at age 7 days. To ensure the uniformity of applying a load, a steel
plate was employed as shown in Figure 6. The test complies with British standard (BS:1881:Part117:1983)[23].

3. Results and Discussion
Concrete workability was significantly affected by the addition of PET waste fibers. Increasing the fiber fractions were lead to decrease the workability, as shown in Figure 7. Similar response to the addition of plastic waste fibers has been achieved by different researchers.

![Splitting tensile specimen](image_url)

**Figure 6.** Splitting tensile specimen

![Graph](image_url)

**Figure 7.** Relationship between slump values and PET fiber fraction variation

Concrete containing 2.5 aspect ratio showed a slump reduction of 16%, 37% and 50% for varying fraction 0.1%, 0.25, and 0.5 %. Concrete with 3 aspect ratio has gained slump relatively more than the previous type in the range between 20%, 41%, and 53%. This reduction may be attributed to the increased ability of fibers to restrict the flowability of the fresh concrete, which impedes the workability.

Test results of compressive strength are shown in Figure 8. Compressive strength was reduced with increasing of PET fiber fractions. Whatever aspect ratio, it is noted that the strength reduction was negligible up to a fiber dosage of 0.5% by volume of the mix. A 2.5 aspect ratio showed a 5% reduction in strength while 3 aspect ratio reduces the strength up to 9%.
It was noted that the mechanism of crack-resisting was enhanced and the material's nature was changed from brittle to ductile due to the effects of PET fibers.

![Figure 8. Relationship between compressive strength and PET fiber fraction variation](image)

Because of PET fibers addition, there was an enhancement in splitting tensile strength in the range of 2–6% and 4–7% for 2.3 and 3 aspect ratio, respectively. Furthermore, crack development was restricted. Figure 9 show test results of splitting tensile strength.

![Figure 9. Relationship between splitting tensile strength and PET fiber fraction variation](image)

### 4. Conclusion

The addition of plastic waste to the concrete led to changes in the properties of fresh and hardened concrete. The workability is inversely proportional to the ratio of waste addition and aspect ratio. As well as the compressive strength is affected by the addition of waste with a slight decrease with the increase in the ratio of addition and aspect ratio. This decrease is due to the weakness of the structure of the concrete and its low density due to the existence of large void around the fibers. As for splitting tensile strength, it has increased significantly. This increase can be explained by the fact that plastic
fibers work to increase the bonding of concrete components and operate with a principle similar to the reinforcing process and act as a conveyer medium for stresses in the cracking area. Test results exhibited good strength of crack-resisting and participated in the ductile response of concrete contain PET waste fibers.

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9
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