Utilising PET Bottle Fibers in the production of Concrete

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Abstract: This study attempts to apply the concept of sustainability by reducing the environmental pollution of plastic waste, especially Polyethylene Terephthalate (PET) that are used in production soft drinks bottles. The plastic bottles were collected, roughened (Roughen the surface by using a metal clip after exposing it to heat, and then place it on smooth surfaces) and shredded into fibres of specific size and shape with an aspect ratio (L/D) of 34.5. Various proportions of PET (i.e. 0.5, 1.0, and 1.5%) have been used in the production of ordinary concrete. The influence of PET fibers on the properties of concrete was studied, such as workability, compressive and splitting tensile strengths. Furthermore, the shear characteristics of continuous reinforced concrete deep beams with dimensions of (150×300×2000) mm produced from such concrete were also investigated. For all percentage of replacements, the fresh property, compressive strength, and tensile strength of PET fibre encapsulated cement concrete were investigated. With the addition of plastic fibre, compressive strength increased marginally, but tensile strength measurements showed a substantial improvement over the control specimen. It has been found that there was an apparent impact of waste plastic fibers on the structural behavior of the investigated beams in terms of its brittleness. The increase in the ultimate load capacity With the increase in the percentage of fiber until a percentage(1%), then it begins to decrease after this percentage of continuous deep beams refers to the use of waste plastic fibers to improve the tensile properties of concrete and to limit the spread and width of cracks within the structure.

1 Introduction

The increased necessity for high-rise concrete structures, as a result of the increase in the population density, lack of spaces, urban development and others, has led to considerable attention to the use of deep beam. ACI Code [1] defines deep beams as those "which have a clear span to total depth less than four, or the shear span to the effective depth is less than two and should be loaded on the top face and supported on the bottom face". Thus, compression struts can be developed between loads and support points. The application of reinforced concrete deep beams has appeared in high-rise buildings, offshore structure, foundation walls, transfer girders that support the load from one or more columns as well as in some walls and pile caps. Beams are the more critical part of any concrete structures as they transfer loads to supports or columns and they can suffer from two types of failure such as shear and flexural failure. The former can occur abruptly without sufficient warning unlike the latter failure. Besides, the width crack widths are more significant than those owing to the flexural loads. Figure 1. shows the behaviour of plain and fiber reinforced concrete under tensile load, which is clearly demonstrate the change in failure mode from brittle to quasi-ductile [2].
In the last 20 years, a lot of works concerning the use of several kinds of wastes resulting from industries, have been published due to shortage in natural resources and increasing waste disposal costs [3]. Besides, land-filling of such waste, especially plastic would mean preserving the harmful material forever because plastic is a non-biodegradable material and can pose hazards numerous [4]. They may block the drainage system, which in turn cause flooding and excellent breeding grounds for disease-causing mosquitoes and water borne diseases. They can also affect on the rate of rainwater percolating as it can be reduced due to plastic garbage and deteriorate soil fertility if it is mixed with soil. The water and marine life may also be contaminated by plastic waste that dumped into rivers, streams and seas [4]. Borg et al. 2016 [5] And according to report, increasing the volume fraction of PET fibers reduces compressive strength while increasing flexural strength significantly. Deformed PET fibers, on the other hand, produce better results than straight PET fibers. As a result, the investigators suggest that using recycled PET fibers in concrete may be a viable alternative to PET waste. In a study conducted by Shahidan et al. 2018 [6], Slump, compressive strength, and splitting tensile strength measures were used to determine the best percentages of recycled PET bottle fibers in concrete. PET fibers were used at volume fractions of 0.5 percent, 1 percent, 1.5 percent, and 2.0 percent in concrete mixes, confirming the decrease in compressive strength and value obtained from the slump test. As the percentage of recycled PET fibers is increased, the strength obtained from the splitting tensile test increases. The optimal percentage of PET fibers to be integrated into concrete, according to the findings of this study, was 1.0 percent.

A study has been conducted to use thermosetting plastics into construction materials and considered this application as the most feasible application because most of the methods used for recycling these plastic wastes at present is not economically advantageous, and it is either burying or burning, which leads to emit toxic and polluting gases [7]. Recently, the use of recycled resources has been seen in a variety of fields as a result of environmental and economy concerns as the use of recycled plastic fibers is unquestionably beneficial and significant move toward long-term sustainability. It is widely accepted that using fibre waste reinforcement can significantly improve the tensile characteristics of concrete by bridging the cracks in the matrix and crack opening before being pulled out or torn [8-10]. Shear failure is a very common failure and it cannot provide enough warning before the final failure, which is considered as devastating and fragile.

The use of reinforcement fibers, as is well known using the fibres in concrete Improves the structural and mechanical properties of the building of the structure but, little is known about the effect of waste plastic fibres on the shear strength of concrete members. For this reason, the influence of (PET) fibers on the shear strength of continuous deep beams and mechanical properties of concrete are investigated in this study.
2 Experimental Work

2.1 Material Properties

2.1.1 Cement

Resistant Portland cement, manufactured by AL-JESR / Lafarge Cement Factory, has been used in producing all mixes. The compliance of the cement was carried out according to the Iraqi Standard No. 5/1984[11]. The physical and chemical properties of cement used are presented in Tables 1 and 2, respectively.

| Physical properties          | Result | IQS 5/1984[11] |
|------------------------------|--------|----------------|
| Initial setting time (min.)  | 61     | ≥45            |
| Final setting time (min.)    | 233    | ≤ 600          |
| Compressive strength (MPa)   | 3 days | 15.7 ≥15       |
| (3 days)                     | 7 days | 24.9 ≥23       |

| Oxide          | % by weight | Limits of IQS No.5/1984[11] |
|----------------|-------------|-----------------------------|
| SiO2           | 20.7        | -                           |
| CaO            | 61          | -                           |
| Al2O3          | 4.1         | -                           |
| Fe2O3          | 5.5-5.5     | -                           |
| Lime Saturation Factor | 0.89      | 0.66-1.02                  |
| MgO            | 3.1         | ≤ 5%                        |
| SO3            | 2.3         | ≤ 2.5%                     |
| Loss on Ignition | 3.5        | ≤ 4%                        |
| Insoluble Residue | 0.4        | ≤ 1.5                      |
| (C3S)          | 49.04       | -                           |
| (C2S)          | 22.35       | -                           |
| (C3A)          | 1.56        | ≤ 3.5                      |
| (C4AF)         | 16.74       | -                           |
| Al2O3 / Fe2O3  | 0.75        | -                           |
| Free lime      | 0.78        | -                           |

2.1.2 Fine Aggregate (Sand)

Al-Ukhaidher natural sand has been used in the production of the concrete mixes of this study. The fine aggregates' grading and physical properties are consistent to the Iraqi standard specification (IQS.) No.45/1984 [12] and ASTM C33 specifications (2002) [13], as given in Table 3.
### Table 3: Sieve analysis of fine aggregate*

| Sieve Size (mm) | Passing% | IQS 45/1984 Zone (2) |
|-----------------|----------|----------------------|
| 10              | 100      | 100                  |
| 4.75            | 95       | 90-100               |
| 2.36            | 88       | 75-100               |
| 1.18            | 62       | 55-90                |
| 0.60            | 45       | 35-55                |
| 0.3             | 19       | 8-30                 |
| 0.15            | 3        | 0-10                 |

**Physical properties**

- $SO_3$ (%): 0.3 ≤ 0.5
- Passing 75 µm sieve (%): 1.5 ≤ 5
- Specific gravity: 2.7 ---
- Absorption: 0.8 ---

*This test was made at Al-Qassim Laboratory for structural investigations*

#### 2.1.3 Coarse Aggregate (Gravel)
Crushed gravel (5-20 mm) gradation has been used as coarse aggregate. The gradation, specific gravity, density and sulphate content were tested. Table 4. shows that the grading and sulphate content conform to the Iraqi specification No. 45/1984[12].

### Table 4: Grading and physical properties of coarse aggregate*

| Sieve size (mm) | Passing, % | IQS 45/1984 |
|-----------------|------------|-------------|
| 37.5            | 100        | 100         |
| 20              | 99         | 95-100      |
| 14              | /          | /           |
| 10              | 30         | 30-60       |
| 5               | 0          | 0-5         |
| $SO_3$ (%)      | 0.072      | ≤0.1        |
| Specific gravity| 2.7        | ---         |

*These tests were carried out in the Al-Qassim Laboratory for structural investigations*

#### 2.1.4 Mixing Water
The water used in mix preparation was potable water from the water-supply network system.

#### 2.1.5 Steel Reinforcement
As shown in Plate 1, all beams have been reinforced with bars with diameters of (12) mm for longitudinal reinforcement and (10) mm for transverse reinforcement (stirrups), with the properties of steel reinforcement described in Table 5.
2.1.6 Waste Plastic Fibers (PET-Fibers)

The ribbed (PET) fibers were obtained by shredded soft drink bottles into rectangular pieces with nearly a length of (50) mm, an average width of (5) mm, and thickness of (0.33) mm using a paper shredder, as shown in Plate 2 and Table 6 [14], which describes the physical properties of fibers. The percentages of PET fibers used by volume were (0.5, 1, and 1.5).

| Dimensions (mm) | Aspect Ratio | Density (Kg/m³) | Water Absorption | Colour          |
|-----------------|--------------|-----------------|------------------|-----------------|
| 50×5×0.33       | 34.5         | 1100            | 0.00             | Crystalline White |
2.2 Mix Design

In this regard, the ACI 211 has been adopted to design a concrete mix with 30 MPa as a target 28-days compressive strength. Trial mixes have been carried out to find an appropriate mix that meet the requirement of workability and compressive strength. The properties of the standard concrete mix are shown in Table 7.

| Table 7. Ingredients of concrete mix (kg/m³) |
|---------------------------------------------|
| Cement | Sand | Gravel | W/C |
| 415    | 701  | 1009   | 0.47 |

3 Experimental Program

In this investigation, four reinforced concrete continuous deep beams were cast, all of which have a rectangular cross-section of 150x300 mm with a length of 2000 mm, as shown in Fig. 2. The beams have been engineered as a continuous supported (three support) to fail in shear at the mid-span under two concentrated loads. The tension reinforcements of beams consist of 2Ø12 mm bars at the tension region and 2Ø12 mm bars at the compression region. For the shear resistance, all beams were reinforced with deformed bar of steel with a diameter of 10 mm @ 100 mm and they were crafted following (ACI 318-14) [1], as shown in Fig. 2 and Table 8.

![Figure 2. Continuous Deep Beams reinforcement details](image)

| Table 8. Continuous Deep Beams reinforcement details |
|---------------------------------------------------|
| Beam Specimen | Fibers (%) | a/h | Ln/h |
| BR0%          | 0          |     |     |
| BR0.5%        | 0.5        | 1.5 | 3    |
| BR1%          | 1.0        |     |     |
| BR1.5%        | 1.5        |     |     |
4 Results and Discussion

4.1 Effect of PET Fibers on Concrete Properties

4.1.1 Slump Test
According to ASTM C143 [15], the slump test has been considered to determine the workability of all fresh concrete mixes. Results showed that PET fibers had an effect on the slump test results. The workability became lower as the added volume of PET fibers increased, while the percentage of w/c remained unchanged, as shown in Fig. 3. The reason behind such behaviour could be due to the high surface area of the concrete components, which requires high amount of water to keep the same value of slump. The form of fibers can restrain the movement of the concrete constituents, which could be considered as another reason for such reduction in its workability.

![Figure 3. Effect of (PET) fibers on workability](image)

4.1.2 Compressive Strength Test
Three cubes with dimensions(150x150x150) mm were used to measure each the compressive strength of various prepared mixes with various PET fiber volume fraction at the ages of (7) and (28) days, as shown in Table 9, which represents the average of the results. The results revealed that there was a minor impact of fiber on the compressive strength of concrete at (7) days and that the strength decreased as the percentage of fibers increased. As for the age of (28) days, the compressive strength dropped with raising the (PET) fibers percentage. The slight decrease in the compressive strength at (7) days can be explained in two ways: the (PET) fibers acts as strengthening bridges, binding the parts of the cement paste at the early stages of the curing period when it is still weak and fragile due to incomplete hydration interactions. The other reason is that the presence of fibres in the mix increases the amount of absorbed energy before failure, which has a minor impact on loading potential at early ages. On the other hand, one explanation of the reduction in the compressive strength at the age of (28) days with fiber percentages of 1% and 1.5 per cent is that the (PET) fibers reflected defects in the cement paste that became apparent. Figure 4 illustrates the relationship between the compressive strength and fibers percentages at various ages.
Figure 4. Relationship between the compressive strength and fibers percentages

Table 9. Concrete's compressive strength for all fiber percentages

| Fiber % by vol. | $f'_c$ (MPa) 7 days | $f'_c$ (MPa) 28 days | percentage change % |
|----------------|---------------------|---------------------|---------------------|
| 0              | 22.7                | 30.0                | --                  |
| 0.5            | 21.6                | 28.6                | -4.66               |
| 1.0            | 20.7                | 27.0                | -10                 |
| 1.5            | 20.3                | 26.0                | -13.33              |

4.1.3 Splitting Tensile Strength Test

As shown in Fig. 5. and Table 10, At (7) and (28) days, the splitting tensile strength of a standard cylinder (100X200 mm) was tested. for all mixes with various PET fiber percentages according to ASTM (C496-86) [16].

Figure 5. Relationship between fiber percentages and splitting tensile strength
Table 10. Splitting tensile strength and fibers percentages and max. axial crack

| Fiber% by vol. | $f_t$ (MPa) 7 days | $f_t$ (MPa) 28 days | Max. Axial Crack Width (mm) |
|---------------|-------------------|-------------------|-----------------------------|
| 0             | 1.30              | 1.39              | --                          |
| 0.5           | 1.34              | 1.42              | 1.12                        |
| 1.0           | 1.50              | 1.60              | 0.80                        |
| 1.5           | 1.75              | 1.90              | 0.62                        |

The results showed that the splitting tensile strength increased as the percentage of (PET) fibers increased until the percentage of (PET) fibers reached (1.5 %). In contrast to the control specimen, which split into two sections after the test, the specimen parts have a strong cohesion together after failure. It was also discovered that the control specimen split abruptly with a loud sound, while the cylinders with fiber percentages (1 per cent and 1.5 per cent) made no audible sound, which could refer that using (PET) fibers can make concrete more ductile. This behaviour was already expected with the presence of fibers is due to an increase in the interdependence of cement paste, which causes internal stresses to be reduced and the ultimate applied load to be increased.

4.2 Effect of PET Fibers on Reinforced Concrete Continuous Deep Beams Behaviour

As described earlier, four continuous reinforced concrete deep beams with two spans were prepared, including the control beam. On the other hand, beams RB0.5%, BR1% and BR1.5% were prepared from concrete that have three percentages of fibers (0.5, 1, and 1.5%) in addition to one reference beam (Beam BR0%) with no fiber for comparison. All beams were subjected to a two-point bending test until shear failure. Table 10 shows clearly all detail of the experimental results of various beams. The experimental findings in terms of failure loads, modes of failure, crack patterns, and deflection profile will be described and discussed.

4.2.1 Failure Loads

Table 11 and Figure 2 below provide descriptions and details of beam specimens. Almost all beams fail in shear when they approach their failure load, according to research. This expected behaviour was mainly due to the inclusion of nominal stirrups at the shear zone compared to the longitudinal reinforcements for flexure. At failure, the load values were higher than the control beam (BR0%), which registered a load of only 350 kN. RB0.5%, BR1% and BR1.5% could be considered to be shear strengthened by the addition of the fibers of various percentages in each (0.5, 1, and 1.5%), respectively. At failure, with a load of 360 kN, BR1% reached the maximum load. whereas RB1.5% recorded lower load failure of 320 kN. At 355 KN, the most failure load was reported for BR0.5 %. As observed, most of the maximum failure load value for the beams with PET fibers was greater than that of the control beam (at 350 KN) with the exception of BR1.5% that recorded the lowest failure load than the control beam. Besides, the shear contribution of PET fibers in RB0.5%, BR1% were +1.43% and +2.86% in comparison with the control beam. From the results, it can be concluded that the optimum fibers percentage that provide better shear enhancement was (1%). The role of waste plastic ribbed fibers in improving the tensile properties of concrete and limiting the spread of cracks within the concrete body is referred to as increasing the ultimate load strength of beams. It is worth mentioning that a decrease in the ultimate load of BR1.5% that had fibers percentage of (1.5%) is possibly as a result of the loss the concrete workability that made it more porous. In other words, the presence of fibers causes a loss of mix homogeneity and balling of fibers.
Table 1. The ultimate shear strength of all continuous deep beams.

| Beam Specimen | Fibers (%) | a/h | Ln/h | Failure Loads (KN) | % of load failure change |
|---------------|------------|-----|------|--------------------|-------------------------|
| BR0%          | 0          |     |      | 350                | -                       |
| BR0.5%        | 0.5        | 1.5 | 3    | 355                | +1.43                   |
| BR1%          | 1.0        |     |      | 360                | +2.86                   |
| BR1.5%        | 1.5        |     |      | 320                | -8.58                   |

4.2.2 Failure modes and crack patterns

Table 12. The control beam and beams with different fiber content display the first crack load, failure loads, width of crack and maximum deflection. Plates 3 and 4 show the crack patterns, critical shear crack line, and failure modes for all four beams in greater detail. Plate 3 depicts the crack pattern and failure mode for BR0%. Shear crack lines were more distinct than flexural crack lines, as predicted. The first crack in the beam was observed at a load of 70kN. When the load was gradually increased, flexural cracks were initiated before the shear cracks stopped propagating. The crack pattern and failure mode for BR0.5% are shown in Plate 4(a). Shear cracks began to propagate from the inner support and extended towards the point load at a load of 80kN for BR0.5%. As the load increased, shear cracks began to propagate from the inner support and extended towards the point load. When it hits its 355kN failure load, In shear, BR0.5 % failed. At the same time. There were also noticeable signs of cracks and crushing on the top-side of the beam at the time of failure. The mode of failure for this beam for BR1% was shear, as shown in Plate 4. (b). One of them finally split, creating large cracks on the side of the beam prior to failure. The first crack in BR1% occurred at a load of 100kN, and subsequent increases in load caused it to fail at a load of 360kN. The beam failure for BR1.5 %, as shown in Plate 4(C), appeared at a failure load of 320kN, causing the beam to fail in shear., it was clear that one types of failure modes have distinctly occurred: 1. Shear failure of the 2-span continuous RC deep beam. The Microscope was used to measure the width of wider diagonal cracks in order to determine the fibers' contribution to the concrete's stability after failure. The wider diagonal crack's width of beams was reduced as the percentage of fibers increased in Table 11; this behavior refers to increasing the interconnection and attraction points between the separate beams. PET failure cracks in beams are much finer and less in number than BR0 percent failure cracks. Since fibers strengthen the internal bonding of concrete material parts, this is the case. Furthermore, the PET beams failed in a gradual and ductile fashion, while the non-fiber versions failed abruptly and brittlely.
| Beam Specimen | First Crack (KN) | Mode of Failure | Maximum Deflection (mm) | Width of the large diagonal crack (mm) |
|---------------|------------------|----------------|-------------------------|----------------------------------------|
| BR0%          |                  | S              | 4.00                    | 1.2                                    |
| BR0.5%        |                  | S              | 3.90                    | 0.92                                   |
| BR1%          |                  | S              | 4.25                    | 0.70                                   |
| BR1.5%        |                  | S              | 3.75                    | 1.01                                   |
4.2.3 Load-Deflection records or curves

Figure 6 show the relationship between the load and mid-span deflection for all beams. Details of the maximum deflection of all beams are clearly shown in Table 12. All beams had a deflection profile that was identical to BR0 %, but with a stiffer response. The different percentages of fibers have a slight impact on the deflection profile of the beams, according to this observation. The maximum deflection recorded for all beams smaller than deflection for BR0% . The trend indicated that using fibers can improve the beam's stiffness and ductility conduct. The curves show that the presence of waste plastic fibers that served to bridge the cracks reduced the value of deflection at the same load level. It's worth mentioning that the existence of waste plastic fibers reduced the beam's deflection at the first crack only slightly, since plastic fibers’ resistance to tensile stresses began at the beginning of the crack's development. Using steel fibers, however, the resistance to tensile stresses begins before the first crack appears, resulting in an increase in the load of the first crack and a major reduction in beam deflection. Both types of fibers, in general, can bridge cracks and redistribute stresses in the beam body, allowing it to bear more load with a smaller deflection at the same load amount.
5 Conclusions
The use of PET fibers in casting continuous reinforced concrete deep beams of three percentages (0.5, 1, and 1.5 percent) was investigated experimentally. Four beams were subjected to a two-point bending test with a shear span to effective depth ratio of 1.5 in order to complete this research. Some of the essential points that can be deduced from the experimental findings are as follows:

5.1 Material properties

1. The increasing of waste plastic fibers percentage led to decreasing workability of concrete mixes and the value of this decrease was almost (25%) at fibers content (1.5%).
2. Experimental results showed the effect of waste plastic fibers on the compressive strength of concrete was slight for all fibers percentages with an almost of (5.95 %) at (7) days and (8.47 %) at (28) days with 1.5%. However, there is no increasing in compressive strength for higher values of PET% due to fiber collections during process of mixing.
3. PET effect on splitting tensile strength more than the compressive strength. Increased the splitting tensile strength with increasing of fibers content until the percentage of (1%) that recorded a significant increase in tensile strength by (15.18%) at 28 days. Besides, the width of the axial crack for the tested cylinders became very small after failure with incorporating the waste plastic fibers.

5.2 Experimental results of PET continuous deep beam

1. The shear strength and absorbed energy of reinforced concrete beams were increased with incorporating the plastic fibers in concrete until the fibers percentage of (1%) that recorded an increase in the applied load by about (2.86%) compared to control beam.
2. A increasing in the first crack load has been observed with increase (PET) fibers content until (1%), which recorded equal to (42.86%)
3. The experimental tests showed that the width of first crack decreased with increasing of fibers content at the same load, which reflect the improved performance of RC deep beams with fiber (PET).
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