Flexural behaviour of reinforced concrete beams containing waste plastic fibers

A. I. Al-Hadithi¹, M. B. Abdulrahman² and M. I. Al-Rawi²

¹University of Anbar, College of Engineering, Dams and Water Resources Engineering Department, Ramadi, Anbar, Iraq.
²University of Anbar, College of Engineering, Civil Engineering Department - University of Tikrit, Tikrit, Iraq.

Email: al_hadithi2000@yahoo.com

Abstract. This research was conducted to study the effect of adding waste plastic fibers (WPFs) on the behavior of reinforced concrete (RC) beams. Fifteen simply supported RC beams with a cross section of (100 * 150) mm and a clear span of (1100) mm was tested under two-point loads until failure. Three beams of the total samples were made from the reference mix, and the twelve beams remaining were made from concrete mixes containing WPFs with volumetric percentage ratios ($V_f$) varying from (0.5% to 2%) of the total volume. These beams were divided into three main groups according to the longitudinal steel reinforcement area ratio ($\rho$), and these ratios were approximately equal to ($\rho_{\text{max}}$, $0.75 \rho_{\text{max}}$, $\rho_{\text{min}}$). Test results established that the adding of WPFs, in addition, to decreasing the danger of PET wastes on the environment, leads to increasing the maximum applied load causing ultimate failure, an increment in ductility index and transformation of the mode of failure of the tested beams into a more ductile one for all beams contains such kind of fibers.

Keywords
Fiber Reinforced Concrete, Waste Plastic Fiber, PET, Mechanical Properties, flexural behavior.

1. Introduction
Wastes today represent a serious challenge on the environmental and human health. The continuity of producing these wastes leads to collapse in our life-system and to increase in the toxicity in the earth, rivers, oceans, and air. Engineers do their best for reducing pollution by including many forms of wastes in the construction industry. Plastic is one of the famous waste materials. Because of the contribution of plastic in many domestic productions like beverage bottles, food packaging, and other consumer good containers, plastic wastes occupied a wide range all over the industrial wastes. Inclusion of polyethylene terephthalate (PET) residues inside the concrete structure as aggregate or fibers recorded as attempts to decrease the negative effects of PET wastes on the environment, and to benefit from these wastes to modify some concrete properties quality by many researchers [1-11]. Many studies deal with flexural behaviour of reinforced concrete members containing several types of synthetic fibers but a little study the effects of adding waste fibers for such kind of behaviour. Few studies studied the behavior of reinforced concrete members made from concrete containing waste plastics. Mohamed [12] described through his research the results of testing and analyzing the flexural behavior of reinforced concrete beams made of recycled PET waste concrete. Results of this research proved that, for producing recycled reinforced concrete beams for structural applications, well-graded PET particles up to volumetric ratio equal to 15% can be added.
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Irwan et al [13] studied the effects of adding irregular-shaped Polyethylene Terephthalate fibres (IPET) on the deflection of reinforced concrete beams. This paper reports the results on deflection behaviour of reinforced concrete beams conducted using (IPET) as a fibres. The IPET fibres were added with volume of fraction ranged from 0.5% to 1.5%. Reinforced concrete beams were tested under four point loading under flexural capacity behaviour. The results for deflection behaviour namely cracking stage, yield stage and ultimate stage and ductility are reported. It is found that the addition of IPET fibres improves the first crack and ultimate strength as well as ductility of reinforced concrete beams proportional to the increment of volume fraction of IPET fibres. Based on the results of tested beams, the addition of IPET fibres significantly increases the deflection behaviour of these beams. Al-Hadithi et al [14] studied the shear behavior of waste plastics fibers reinforced concrete beams. In this research the steel stirrups which were used for shear reinforcement replaced by carbon fiber reinforced polymer (CFRP) slips coating by epoxy. WPFs were added as volumetric fraction equal to (0.25, 0.5, 0.75, 1, 1.25 and 1.5) %. Reference beams were made using steel stirrups. Results indicated that shear strength increased by 11.45% and 8.45% for the beams reinforced with CFRP strips and steel stirrups, respectively, at 1% fibres content. Similarly, shear ductility increased by 8.61% and 9.96% for the beams reinforced with CFRP strips and steel stirrups, respectively, with an increase of up to 1.25% in fibres content.

This experimental study was aimed at investigating the influence of adding different volumetric ratios of waste plastic fibers (WPFs) on the first cracking load, mid-span deflection at first crack, ultimate load, mid-span deflection at ultimate load and average flexural stiffness of reinforced concrete beams which were reinforced with three different steel reinforcement ratios.

2. Experimental Program

2.1. Materials

Ordinary Portland cement was used in casting all beams throughout the experimental work. Tests of physical and chemical properties and the analysis proved that this type of cement conforms to the Iraqi Specifications I.Q.S. 5/1984 [15]. For producing all concrete mixes, natural sand was used with a maximum aggregate size of 4.75mm. The fine aggregate was washed to remove any clay. The sieve analysis and physical properties of fine aggregate conform to the Iraqi Specifications I.Q.S. No.45/1984 [16]. Crushed gravel with a maximum size of aggregate equal to 14mm was used as coarse aggregate. The sieve analysis and physical properties of this aggregate proved that this aggregate conforms to the Iraqis specifications I.Q.S. No.45/1984. Rectangular shape of waste plastic fiber was used throughout this research. The waste fibers were made by shredding beverage bottles made of (PET) into regular shapes and dimensions using shredder machine. Fibers were added to the mixes as a ratio by volume of a mixture of 0.5%, 1.0%, 1.5%, and 2%, respectively. The geometrical characteristics of plastic fibers used throughout the experimental work are illustrated in Table 1. 12 mm, 10 mm, and 6 mm steel bars had been used for all types of steel reinforcement as a flexural reinforcement for all lengths of the beam. The average yield strength is (591 MPa, 580 MPa and 564 MPa), and the average ultimate strength is (687 MPa, 672 MPa and 652 MPa) for 12 mm, 10 mm, and 6 mm steel bars, respectively. A 6 mm steel bar has been used as shear reinforcement (the stirrups). The steel bars are tested according to ASTM A 615/A 615M – 03 [17].

| Type of Fibers | Average Length (mm) | Average Width (mm) | Average Thickness (mm) | Specific gravity |
|----------------|---------------------|--------------------|------------------------|-----------------|
| Plastic fibers | 30                  | 4                  | 0.30                   | 1.12            |

2.2 Description of beams

Fifteen reinforced concrete beams were tested under the applied point load transfer into a two-point
load on the beam point loading system. In all beams, the cross section was 100 mm wide and 150mm in depth, the overall length was 1200mm with clear span of 1100mm. The beams were designed to have extra strength in shear to ensure flexural failure even after strengthening; therefore, the shear span was reinforced with $\phi \, 6\text{mm} @ 60\text{mm}$ as shear reinforcement in all beams as shown in Figure 1.

![Figure 1. Details of the reinforcement in the beam specimen](image)

The main variables that have been considered in this study include the amount and yield strength of the tension steel reinforcement and the waste plastic fiber contains. As shown in Figure 2 below, detail of the compression steel bars was $2\varnothing 6\text{mm}$ in all beams. The longitudinal reinforcement was reinforced with three different steel reinforcement ratios which were approximately equal to $\gamma_{\text{max}}$, $0.75\gamma_{\text{max}}$, and $\gamma_{\text{min}}$, respectively, which were represented by a number of bars at tension zone equal to $2\varnothing 6\text{mm}$, $2\varnothing 10\text{mm}$, and $2\varnothing 12\text{mm}$ at bottom of the beams, respectively.

![Figure 2. Reinforcement details of the beam sections](image)

A load cell and a dial gauge were used to read the load and measure the mid span deflection, respectively. The dial gauge was placed directly under the center-line of the beam in order to record the mid-span deflection at every load stage as shown in Figure 3. Deflection for each beam was recorded for each 7.6 kN in loading incremental. The load and deflection were recorded during observation. The testing continued until the failure of beams occurred. Figure 3 shows the tested beams.
2.3 Mix Design:
Several trial mixes were done to indicate the suitable mix proportion for obtaining the required concrete compressive strength. The final mix was (1: 1.5: 3.15) with water to cement ratio 0.43 and five different waste plastic fiber contain was (0%, 0.5%, 1%, 1.5%, 2%). The target value of compressive strength was 30 MPa.

2.4 Testing of Compressive Strength
Compressive Strength: The compressive strength test was determined according to ASTM C39/C39 [18]. This test was conducted on 100mm cubes using the digital hydraulic testing machine (ELE) with a capacity of (2000) kN and rate of 3 kN/sec. The average value of three cubes was adopted for each test. The test was conducted at age of 28 days.

3. Results and Discussion:
3.1 Compressive strength
The results of testing of compressive are illustrated in Table 2. From this table, it can be noticed that, the compressive strength increases with the increase of WPFs contains until (Vf=1%), after that, the compressive strength decreased. Compressive strength of concrete cubes increased when plastic fibers were added and the maximum value of that increment was when (Vf=1%) and it is equal to about (10%). This increment can be attributed to: the WPFs are regularly distributed inside the structure of the concrete mixture and this leads to increase in the homogeneity and decrease in the voids amount within the concrete body and makes it more cohesive and harder. When micro-cracks begin to evolve inside the matrix, WPFs try to arrest the propagation of these kinds of cracks in the neighboring region development and limiting this propagation. As a result, this leads to winding the path of propagation of cracking, and thus needs more energy for the continuation of crack propagation, and therefore this operation needs to get to high stresses for the existence of failures [2]. After that, there will be a decrease in compressive strength. The reason of decreasing after (1%) is because the WPFs had formed bulks and segregate on the mix.

3.2 Flexural Behaviour of Reinforced Concrete Beams
The results for fifteen tested beams are observed and controlled. First the fracture samples at failure were observed, second, controlled load at first cracking and the ultimate stages and their associated mid-span deflections were observed. Then, the applied loads versus the deflection at the mid span of the beams for all specimens were noted.

From Table 2 below and from figures (4, 5, 7 and 9), it can be clearly noticed that effects of adding WPFs with volumetric ratio varied from 0.5% to 2% on the behavior of RC beams as concluded in the notes below:
- Adding of WPFs leads to increase in the values of the loads causing first cracks and ultimate failures as compared with beams produced by reference Mix for all steel reinforcement ratios
which are used in this study ($\rho = \rho_{\text{max}}, 0.75 \rho_{\text{max}}$ and $\rho_{\text{min}}$). The use of the volumetric ratio of adding WPFs equal to (1%) achieved the highest increase in the value of the first crack and maximum load in all reinforcement ratios.

- The addition of WPFs causes decrease in both values of ultimate deflection (at failure) and first crack deflection as compared with beams produced by reference Mix for all steel reinforcement ratios. The lowest values of deflections were recorded for using WPFs with volumetric ratio equal to (1%) in all beams with different reinforcement areas.
- Elevating the amount of average flexural stiffness ($Pu/\Delta u$) value with an increase in WPFs ratio by volume value: the largest average flexural stiffness AFS value for all RC beams tested in this paper was accomplished by adding WPFs with ($V_f=1.5\%$).
- The role of amount of steel reinforcement area more clearly appeared in the behavior of RC beams in the ultimate failure stage.

**Table 2:** Numerical values for the parameters of the flexural behaviour

| Beam No. | WPF % | As (mm$^2$) | $\rho$ | $f'_c$ (MPa) | $\rho_{\text{min}}$ | $\rho_{\text{max}}$ | $\rho/f_{\text{max}}$ | $P_{cr}$ (kN) | $\Delta_{cr}$ (mm) | $P_u$ (kN) | $\Delta_u$ (mm) | $Pu/\Delta u$ (kN/mm) |
|----------|-------|------------|-------|--------------|----------------|----------------|----------------|--------------|----------------|-------------|---------------|------------------|
| BM1      | 0     | 226        | 0.0182| 32.1        | 0.0162         | 1.1235        | 17.2          | 11.1         | 86.12        | 15.23       | 5.65          |
| BM2      | 0     | 158        | 0.0127| 32.1        | 0.0165         | 0.770          | 14.4          | 1.4          | 65.83        | 13.28       | 4.95          |
| BM3      | 0.5   | 56         | 0.0045| 32.1        | 0.0025         | 0.717          | 11.2          | 1            | 28.98        | 9.02        | 2.18          |
| BM4      | 0.5   | 226        | 0.0182| 33.7        | 0.0168         | 1.082          | 22.9          | 1            | 92.67        | 14.44       | 6.42          |
| BM5      | 0.5   | 158        | 0.0127| 33.7        | 0.0170         | 0.747          | 15.3          | 1.2          | 72.55        | 12.54       | 5.78          |
| BM6      | 0.5   | 56         | 0.0045| 33.7        | 0.0025         | 0.717          | 12.2          | 0.6          | 35.02        | 7.22        | 4.85          |
| BM7      | 1     | 226        | 0.0182| 35.5        | 0.0174         | 1.046          | 24.7          | 0.9          | 102.73       | 13.32       | 7.71          |
| BM8      | 1     | 158        | 0.0127| 35.5        | 0.0177         | 0.718          | 18.5          | 0.75         | 81.35        | 11.16       | 7.28          |
| BM9      | 1     | 56         | 0.0045| 35.5        | 0.0025         | 0.717          | 14.6          | 1.1          | 38.1         | 6.80        | 3.41          |
| BM10     | 1.5   | 226        | 0.0182| 34.6        | 0.0171         | 1.064          | 21            | 1.3          | 95.65        | 12.28       | 7.79          |
| BM11     | 1.5   | 158        | 0.0127| 34.6        | 0.0174         | 0.730          | 17.2          | 1.2          | 75.82        | 9.86        | 7.69          |
| BM12     | 1.5   | 56         | 0.0045| 34.6        | 0.0025         | 0.717          | 12.5          | 0.6          | 35.34        | 6.42        | 5.50          |
| BM13     | 2     | 226        | 0.0182| 33.3        | 0.0167         | 1.091          | 19.3          | 0.8          | 89.04        | 11.90       | 7.48          |
| BM14     | 2     | 158        | 0.0127| 33.3        | 0.0169         | 0.751          | 15            | 0.6          | 69.77        | 9.65        | 7.23          |
| BM15     | 2     | 56         | 0.0045| 33.3        | 0.0025         | 0.717          | 12            | 0.5          | 33.03        | 6.04        | 5.47          |

Where:
- $P_{cr}$: Cracking load
- $\Delta_{cr}$: Mid span deflection at first crack
- $P_u$: Ultimate load
- $\Delta_u$: Mid span deflection at ultimate load
- AFS: Average flexural stiffness = $Pu/\Delta u$

Beams were divided into three main groups according to the longitudinal steel ratio ($\rho = \rho_{\text{max}}, 0.75 \rho_{\text{max}}, \rho_{\text{min}}$) this is done by using steel bars of diameter (12, 10 and 6) mm, as follows below:

**3.2.1 The first group RC beams reinforced with ($\rho_{\text{max}}$).** Figure 3 shows the behavior of RC beams containing different WPFs percentages as (0, 0.5, 1, 1.5 and 2) % under flexural loads. The results show that using WPFs have a good influence in all the beams of this group. Using such kind of fibers, as seen in Figure 5 and Figure 6 had an enhancement in the behavior of RC beams by increasing the Maximum loads causing ultimate failure and by decreasing the value of deflection at the stage of ultimate failure as compared with RC beam made by reference Mix. It can be concluded that, the highest value achieved to reduce the value of maximum deflection was (27.98 %) as compared with beam made by the reference Mix when using WPFs with volumetric value equal to (2%). The maximum increment in the value of maximum applied loads according to reference RC beam was

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equal to (19.29 %), and this was achieved by using WPFs with a volumetric ratio equal to (1%). The significant effects of combination of longitudinal steel reinforcement and WPFs appear more clearly in this group, if compared with the other groups.

![Figure 4. Load – deflection curve of all beams](image)

![Figure 5. Load – deflection curve of RC beams group reinforced with ($\rho_{\text{max}}$).](image)

![Figure 6. Relationship between WPFs, maximum load and deflection](image)

3.2.2 The second group of RC beams reinforced with (0.75 $\rho_{\text{max}}$). The following figure below Figure 7 shows, the behavior of RC beams which are reinforced with (0.75 $\rho_{\text{max}}$) under two-point loads flexural testing. The observations which can conclude from figures (7 and 8) are the same which concluded from paragraph (3-1). The maximum increment in the value of maximum applied loads according to reference RC beam was equal to (23.58 %), and this was achieved by using WPFs with a volumetric ratio equal to (1%). The maximum decrement in the value of maximum deflection
according to reference RC beam was equal to (37.62 %), and this was achieved by using WPFs with a volumetric ratio equal to (2%).

![Graph](image)

**Figure 7.** Load – deflection curve of RC beams group reinforced with (0.75 $\rho_{\text{max}}$).

**Figure 8.** Relationship between WPFs volumetric ratio ($V_f\%$), maximum load and deflection of RC beams group reinforced with (0.75 $\rho_{\text{max}}$).

### 3.2.3 The third group of RC beams reinforced with ($\rho_{\text{min}}$)

The effects of combination of longitudinal steel reinforcement and WPFs appear lower than the other groups, because in this group the minimum area of steel was used for reinforcement of RC beams, but adding of WPFs have had an important effect of the field of increasing maximum ultimate load and decreasing the maximum deflection as compared with RC beam which does not contain WPFs at failure stage. From figures (9 and 10) some conclusion can be concluded, the first is that, the highest value achieved to reduce the value of maximum deflection was (49.34%) compared with beam made by the reference Mix, when using WPFs with volumetric value equal to (2%). The second is that, the maximum increment in the value of maximum applied loads according to reference RC beam was equal to (27 %), and this was achieved by using WPFs with a volumetric ratio equal to (1%).

Generally, through relations between the maximum applied load with deflection in the three groups mentioned above ($\rho_{\text{max}}$, 0.75 $\rho_{\text{max}}$, $\rho_{\text{min}}$), it can be observed that, the highest value got for maximum applied load with deflection when the percentage of fibers (1%), while the highest value of the totals was the third group ($\rho_{\text{min}}$) at fibers (1%) percentage of WPFs and the increment was (31.47%) of the value of the ultimate load caused failure to RC beam made by reference Mix.
3.3 Ductility of RC beams

Ductility is usually defined as the energy absorbed by the material until a complete failure occurs [19]. Ductility index is defined as the ratio between the maximum applied load to the load at yield point which can be found from relationship load – deflection beam when it moved from elasticity to plasticity stage which found by equation (1) below:

$$\mu \Delta = \Delta u/\Delta y$$  \hspace{1cm} (1)

The addition of WPFs to concrete beams, as seen in Table 3 and Figure 11 leads to an increase in the ductility value of these beams. The maximum ductility value was in $\rho_{\text{min}}$ ratio and WPFs volumetric ratio equal to (2%) for beam (MB9). The ductility is important in structure building when its highest value, meaning the building safety avoiding the failure.

The role of WPFs in case of increasing the ductility can be attributed to the same reasons which were mentioned in paragraph (3-1), the WPFs are regularly distributed inside the structure of the concrete mixture and this leads to increases in the homogeneity and decrease in the voids amount within the concrete body and makes it more cohesive and more hard. When micro-cracks begin to evolve inside the matrix, WPFs try to arrest the propagation of these kinds of cracks in the neighboring region development and limiting this propagation. As a result, this leads to winding the path of propagation of cracking, and thus needs more energy for the continuation of crack propagation, and therefore this operation needs to get to high stresses for the existence of failures. That means, adding WPFs to RC beams, gives these beams a wide range of withstanding stress results from external loads,
by giving concrete an extended impact in the field of developing and redistribution of strains and cracks until failure.

Table 3: Numerical values for the parameters of the flexural behaviour

| Beam No. | ρ | ρ max | ρ/ρ max | P_y (kN) | Δy (mm) | P_u (kN) | M_u (kN.m) | Δu (mm) | Ductility Index (μ_d) |
|---------|---|-------|---------|---------|--------|---------|-----------|--------|---------------------|
| BM1     | 0.018 | 0.0162 | 1.1235 | 70.1    | 5      | 86.12   | 17.22     | 15.23  | 3.05                |
| BM2     | 0.0127 | 0.0165 | 0.770  | 50.71   | 4.8    | 65.83   | 13.17     | 13.28  | 2.77                |
| BM3     | 0.0046 | 0.0170 | 0.271  | 18.3    | 2.4    | 28.98   | 5.8       | 9.02   | 3.75                |
| BM4     | 0.018 | 0.0168 | 1.082  | 71      | 4.5    | 92.67   | 18.53     | 14.44  | 3.21                |
| BM5     | 0.0127 | 0.0170 | 0.747  | 51.15   | 4.1    | 72.55   | 14.51     | 12.54  | 3.06                |
| BM6     | 0.0046 | 0.0176 | 0.261  | 20.5    | 1.7    | 35.02   | 7         | 7.22   | 4.25                |
| BM7     | 0.018 | 0.0174 | 1.046  | 71.8    | 3.7    | 102.73  | 20.55     | 13.32  | 3.6                 |
| BM8     | 0.0127 | 0.0177 | 0.718  | 52.12   | 3.6    | 81.35   | 16.27     | 11.16  | 3.1                 |
| BM9     | 0.0046 | 0.0183 | 0.251  | 21.8    | 1.5    | 38.1    | 7.62      | 6.80   | 4.53                |
| BM10    | 0.018 | 0.0171 | 1.064  | 70.7    | 3.7    | 95.65   | 19.13     | 12.28  | 3.3                 |
| BM11    | 0.0127 | 0.0174 | 0.730  | 51.6    | 3.6    | 75.82   | 15.16     | 9.86   | 2.74                |
| BM12    | 0.0046 | 0.0179 | 0.257  | 21.4    | 1.5    | 35.34   | 7.07      | 6.42   | 4.28                |
| BM13    | 0.018 | 0.0167 | 1.091  | 70.3    | 4.1    | 89.04   | 17.81     | 11.90  | 2.9                 |
| BM14    | 0.0127 | 0.0169 | 0.751  | 50.9    | 3.7    | 69.77   | 13.95     | 9.65   | 2.6                 |
| BM15    | 0.0046 | 0.0175 | 0.263  | 18.4    | 1.6    | 33.03   | 6.61      | 6.04   | 3.8                 |

Figure 11. The ductility index value for all RC beams.
4. Conclusions
1. Increasing the proportion of waste plastic fibers (WPFs) reduces the value deflection for all beams.
2. Increasing the percentage of WPFs increases the compressive strength until (ratio 1%) then, the compressive strength is decreased.
3. The maximum applied load on the beam increased extrusive to gather WPFs ratio until (1%) then, it is decreased.
4. The environment in the region was improved by using the WPFs in the fields of concrete.
5. Adding WPFs to RC beams leads to increase in ductility value as compared with RC beams conducted from reference mix.

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