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STRUCTURAL BEHAVIOR OF REINFORCED CONCRETE BEAMS CONTAINING PET WASTE PARTICLES AS SAND REPLACEMENT

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Abstract

This paper examined the polyethylene terephthalate (PET) polymer waste effect that using as a partial replacement for fine aggregate on the R.C beams structural behavior. Six replacement percentages by weight were used in this study: 5 %, 7.5 %, 10 %, 12.5 %, 15 %, and 20 %. Seven concrete beam specimens with dimensions of 150 × 300 × 2300 mm were tested, in which one specimen for each PET replacement percentage was added to the reference specimen. four-point load setting were used to test all specimens via failure load, maximum deflection, energy absorption, stiffness, ductility index, flexural strain, first crack load, and crack pattern. Results showed that raising of PET percentage in the concrete beams leads to an increase in failure load, maximum deflection, ductility index, strain, and energy absorption compared with the reference beam in the ranges 0 – 4 %, 23.2 – 93.7 %, 12.13 – 93 %, 432 – 1139 %, and 51.8 – 275.4 %, whereas its causes a decrease in initial stiffness and secant stiffness in the ranges 5.8 – 38.44 % and 19.2 – 46.4 %. Moreover, crack investigations revealed that the load at which the first crack forms raise when the PET waste content increases.

Keywords:

Reinforced concrete beams;
Polyethylene terephthalate (PET);
Ultimate failure load;
Ductility index;
Initial stiffness.

1 Introduction

The current increase in industrial development and population growth constitutes a large challenge on the environment. Experts believe that the population of the world will raises to about 10 billion people by 2050 [1]. On the one hand, this population growth will place an enormous pressure on the construction and infrastructure needs of countries, that is, increased concrete production demand, which is expected to increase to about 18 billion tons annually in 2050 [2]. On the other hand, the increase in population growth will increase in the solid waste disposal amount. Plastic is considered one of the solid wastes with the greatest effect on the environment because it is non-degradable and remains for even hundreds of years. Polyethylene terephthalate (PET) polymer constitutes the largest percentage of plastic waste due to it is used as a raw material in the production of water bottles, soft drinks, and food packaging. It is one of the materials produced tremendously, especially during the last two decades because it represents a basic need for daily human consumption worldwide. All of the above made researchers think of a way to recycle PET waste and reduce its expected risk on the environment. The characteristics of polyethylene polymer motivated many researchers to study the possibility of using it in concrete. Researchers have recycled those wastes in the shape of fiber or small pieces as a partial or total replacement for concrete components. Concerning the mechanical and physical characteristic of concrete that include PET wastes, many researchers are concerned with recycling PET wastes in concrete mixtures as a fiber with percentages of mix volume in the range of 0.25 % – 4 % and different shapes, dimensions, and slenderness [3-6]. Their shape influence has been discussed for circular strips or short strips [3-6], and long bristles [7] that utilized in concrete mix. The researchers showed increased flexural strength [6, 8] boosted tensile and compression strengths [9], and decreased workability and elastic modulus [8-11]. They concluded

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that the best fiber percentage ranges between 1 % to 1.5 % [6, 8, 10]. By contrast, few researchers addressed the recycling PET fibers influence on the structural behavior of reinforced concrete beams. Ochi et al. [8] used four volumetric percentages 0 %, 0.5 %, 1.0 %, and 1.5 % of PET bottle fiber with a 30 mm as a maximum length in concrete mixtures. The results showed that bending strength, absorbed energy, and toughness increase with the increased percentage and 1.5 % is the optimum fibers percentage. Kim et al. 10] investigated the effect of three PET fiber volumetric percentages of 0.5 %, 0.75 %, and 1 % on the structural behavior of 2000 × 200 × 300 mm reinforced concrete beams. They showed that PET fibers enhance tensile resistance, delay crack figuration, boost ductility and load capacity, and raise the mid span deflection nearly to 400 % greater than the reference specimens. Khalid et al. [9] used two shapes of PET waste fiber in 150 × 300 × 2500 mm reinforced concrete beams. The first form is non-irregularly shaped particles with dimensions ranging from 5 mm to 20 mm. The second is ring-shaped PET fibers with diameters of 60 ± 5 mm and two widths of 5 ± 1 and 10 ± 1 mm, respectively. They found that concrete beams containing ring-shaped pet fiber (width 10 mm) raise initial crack strength by 32.3 %. Adnan and Dawood [11] used two types of PET fiber waste, namely, uniform hand fibers and unequal machine fibers, with two volume percentages for every type, namely, 1.5 % and 3 %, in four 150 × 200 × 1400 mm concrete beam specimens to investigate their structural behavior. The result exhibited a slight decrease in the load capacity and secant stiffness of the beams. However, a notable mounting in ductility behavior and an increase in the initial stiffness were observed. In the field of using PET waste as a sand partial substitute by weight percentages in concrete mix, most researchers discussed its impact on the concrete properties too. Their results differed with regard to the mechanical properties of concrete due to the variation in the form, size, and ratio of the PET waste particles used as a fine aggregate partial replacement. Several studies using PET particles with a max size ranging between 10 to 15 mm and by weight replacement ratios ranging from 5 % to 75 % recorded a reduction in the concrete mechanical properties, a decrease in the modulus of elasticity and workability, and an increase in ductility [12, 13]. With a decrease in the PET particles size as well as the percentage of substitution, the researchers observed an improvement in the mechanical parameters of concrete. Azhdar Pour et al. [14], and Dawood et al. [15] showed that utilization PET waste particles with a measurement in the range of 2 – 7 mm and percentages in the range of 5–30 % as a sand fractional substitution in concrete mixture produces an optimum compressive strength at a 5 % substitution percentage. They also found a diminution in slump, elastic modulus, and pulse velocity when PET waste content increases. The impact of recycling PET waste as main reinforcement bars on the concrete beams structural behavior was also tested [16, 17]. The current study is unique as it one of the few studies that dealt with the effect of using polyethylene terephthalate waste as a partial substitute for sand on the structural behavior of reinforced concrete beams. The PET waste employed in this study was cut into small pieces with various sizes that pass-through sieve No.4. Six various percentages of PET waste 5 %, 7.5 %, 10 %, 12.5 %, 15 %, and 20 % used as a partial substitute for sand were distributed to six reinforced concrete beams with dimensions of 150 × 200 × 2300 mm in addition to reference beam. Structural behavior of all beams was verified via a set of tests. The use of PET plastic waste in construction works provides three essential benefits: reducing its negative effect on the environment, increasing its positive impact on the structural behavior of concrete members, and providing a sustainable material that can be used as a partial alternative to aggregates, which contributes to prolonging its sources.

2 Experimental methodology

The work program includes studying the PET waste particles influence on the reinforced concrete beams structural behaviour when it used as partial substitute for fine aggregate with various percentages

2.1 Materials characteristics

All materials used in this study were satisfying the Iraqi standard specifications. Ordinary Portland cement Type I was used. Its physical properties summarized in Table 1, which satisfy the requirements of Iraqi Specification IQS 5/1984 [18] and ASTM C150-2004 [19]. Iraqi natural sand with a maximum size of 4.75 mm was used as fine aggregate. Coarse aggregate with a maximum size of 20 mm was used as gravel. Tables 2 and 3 summarize the grading of the fine aggregate and PET particles with limits of Iraqi standard specification IQS 45/1980 [20] and ASTM C33-2003 [21]. Super plasticizer conformed to ASTMC494-99 [22] types A and G, was used. Small and large waste bottles

of PET were used. PET waste bottles with various shapes, sizes, and colours were collected, washed, and minced to very small particles passing through sieve number 4, as shown in Fig. 1. It was brought from the local recycling factories. The sieve analysis of PET particles showed that their grading is acceptable compared with the sieve analysis of sand according to Iraqi Specification IQS 45/1980 [20], as presented in Table 2. The weight mixing ratio was (1:1.5:3) and the target strength was of 35 MPa. The water to cement ratio of 0.4 with 0.4 % super plasticizer was selected. Waste of PET bottles was used as a sand partial replacement in six proportions and the reference mixture. The weight percentages of PET waste used in this study were 5 %, 7.5 %, 10 %, 12.5 %, 15 %, and 20 % of the weight of sand. Table 3 shows the concrete mixture percentages, while Table 4 presents the mechanical properties of concrete for each mixing ratio.

2.2 Steel distribution

Deformed rebar with 12 mm diameter were selected for main reinforcement while rebar with 10 mm diameter were used as shear reinforcement. Table 5 exhibits the properties of the used reinforcement bars. All beams were reinforced by 3 ϕ 12 mm bars at the tension zone and 2 ϕ 12 mm bars at the compression zone. Stirrups with a diameter of ϕ10 mm spaced at 60 mm c/c were used at shear span while the middle portion was spaced at 120 mm c/c, as shown in Fig. 2. The flexural beam reinforcement was designed according to ACI 318-2014 [23] Code to ensure that the beam fails in flexure, with tension-controlled failure mode.

Table 1: Cement physical properties.

Physical properties	**Test result**	**Limits of Iraqi specification IQS.5/1984 [18]**	**Limits of ASTM C150-04 [19]**
Fineness using Blain air permeability apparatus [m^2/kg]	384	≥230	≥ 280
Setting time using Vicat's method			
Initial [hours: minutes]	2:00	≥ 0:45 minutes	≥ 45
Final [hours: minutes]	3:45	≤ 10 hours	≤ 3.75
Soundness using autoclave method	0.22	< 0.8	-
Compressive strength of mortar			
3 days, [MPa]	20.8	≥15	≥12
7 days, [MPa]	27.4	≥23	≥19
28 days, [MPa]	34.7	-	-

Table 2: Fine aggregate and PET waste particles grading.

Sieve size [mm]	**Sand percent passing [%]**	**PET percent passing [%]**	**Cumulative passing limits of Iraqi specification IQS.45/1980 [20]**	**Cumulative passing limits of ASTM C33-2003 [21]**
10	100	100	100	100
4.75	95.6	95.6	90 – 100	95 – 100
2.36	85.73	97.64	75 – 100	80 – 100
1.18	72.04	18.72	55 – 90	50 – 85
0.60	48.25	2.55	35 – 59	25 – 60
0.3	17.75	0.5	8 – 30	5 – 30
0.15	3.7	0.19	0 – 10	0 – 10

Table 3: Concrete components ratios for all PET replacement percentages.

Material [kg/m^3]	**0 %**	**5 %**	**7.5 %**	**10 %**	**12.5 %**	**15 %**	**20 %**
Cement	444.75	444.75	444.75	444.75	444.75	444.75	444.75
Sand	667	633.65	616.975	600.3	583.625	566.95	533.6
Gravel	1334	1334	1334	1334	1334	1334	1334
Water	177.9	177.9	177.9	177.9	177.9	177.9	177.9
PET	0	33.35	50.025	67.7	83.3	100.05	133.4
SP	1.779	1.779	1.779	1.779	1.779	1.779	1.779

Table 4: Mechanical properties of all concrete mixes.

PET/Sand [%]	Compressive strength [MPa]	Tensile strength [MPa]	Flexural strength [MPa]
0	29.75	2.41	4.53
5	39.8	2.6	5.76
7.5	42.2	3.06	5.9
10	38.1	2.87	5.72
12.5	36.9	2.86	5.35
15	30.22	2.43	4.55
20	27.84	2.32	4.35

Table 5: Steel reinforcement bars properties.

Bar type	Bar diameter [mm]	Bar area [mm^2]	Yield strength *fy* [MPa]	Tensile strength *fu* [MPa]	Yield strain
Longitudinal steel bars and stirrups	10	78.5	515	624	0.00258
Longitudinal steel bars	12	113.04	493	583	0.00247



Fig.1: PET waste particles used in the study.

2.3 Test specimen's preparation

Fine and coarse aggregates were washed and dried before use in mix. The forms were prepared, cleaned, and lubricated before casting, as shown in Fig. 3a. Seven forms with dimension of 150 × 300 × 2300 mm were prepared. The same reinforcement detail was adopted for all beams. The variables in this study were PET waste particle percentages, which were prepared and mixed as a sand partial replacement with the weight ratios indicated above in the concrete beams. Mixing was done by an electric mixer for each percentage separately. First, fine aggregates including PET waste particles were added. Subsequently, coarse aggregates and cement were added and mixed for homogenization. Then, water and additive were added gradually. The mixing processes were stopped at least 2 minutes after mixing. Then the forms were filled with fresh concrete in the form of two layers, each layer was compacted by vibrator, and the outer face of the forms was levelled. After 48 hours, the forms were opened, and the specimens were wrapped in a cotton cloth that retained moisture. Moisturizing continued during the 28-day curing period, as shown in Fig. 3b. All samples were tested after 35 days from the date of casting.

2.4 Loading setup and instrumentation

Two points' monotonic loads' setting (namely, four-point bending test) was used to test every beam. The ratio of shear span to effective depth *a/d* was of 2.5. Fig. 4 clarifies the details and method of the test setup. The simply supported beam specimen was laid on two steel rollers supports at 150 mm (calculated from the edge of the beam). The 2000 mm specimen clear span was divided into three portions; the middle portion of the length between applied forces was 680 mm while the length of each end portion was 660 mm. A testing machine of 600 kN capacity was utilized to apply the concentrated load on a distributor beam that produced two concentrated loads on the test beam. Steel plates and rubber pads were placed above the supports and underneath the loading points to avert the topical

crushing of the tested beams. The beam specimen's deflection was measured by using a 100 mm capacity dial gauge with 0.01 divisions that placed at the mid-span of the beam. Electrical strain gauges with 30 mm length and 120 ohm resistance were also pasted on the side concrete surface. The midspan compressive concrete strain was measured by two strain gauges (one in the compression zone and one in the tension zone). During test, a data logger was utilized to record and save the test data, which were later forwarded to a computer for more working. The behavior of the beams, all cracks, and failure modes were recorded throughout the test. The tests were performed for each beam via ultimate load failure, ultimate deflection, energy absorption, stiffness, ductility index, and strain. Crack investigation including first crack load and crack pattern were also investigated then compared with the reference beam.

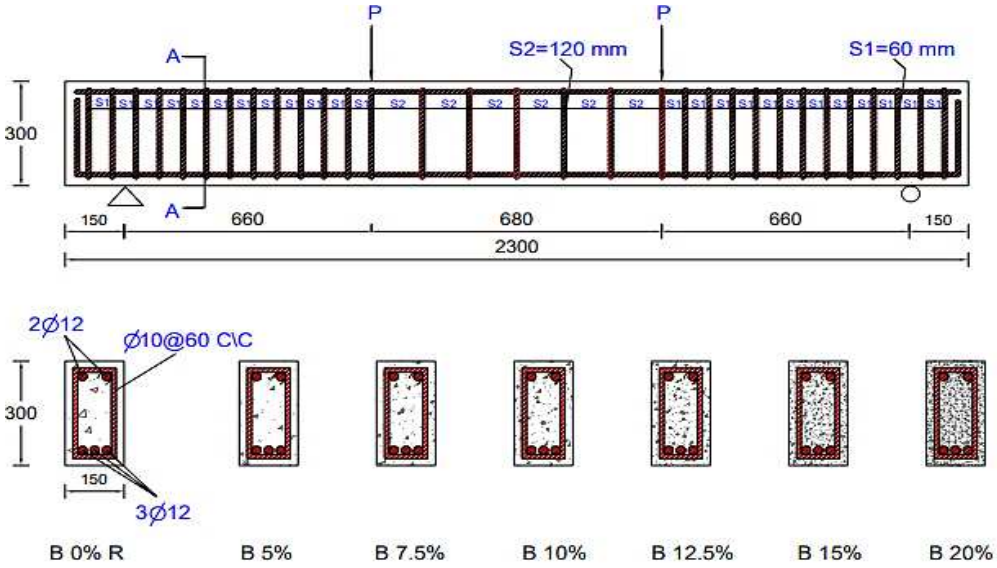


Fig. 2: Specimens 'steel details for all beams.



Fig. 3a: Preparation of beam specimens.



Fig. 3b: Casting, curing method, and beam specimens.

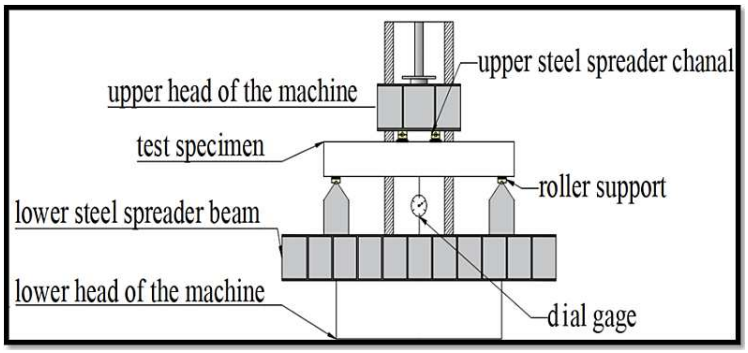


Fig. 4a: Loading setup and instrumentation.



Fig. 4b: Loading setup method.

3 Results and discussion

3.1 Beam ultimate load

All concrete beams had relatively close results of ultimate load failure, as shown in Fig. 5a. The results indicate that the increase in the PET content in the concrete beams leads to a slight increase in ultimate failure load, except for concrete beams B 5 % and B 12.5 % containing replacement ratios of 5 % and 12.5 %, respectively, which were close to the results of the reference beam. The reference concrete beam recorded an ultimate failure load of 164.9 kN, whereas concrete beams B 7.5 %, B 10 %, B 15 %, and B 20 % recorded ultimate failure loads of 165.4, 166.2, 168.7, and 171.5 kN, respectively, with increases of 0.30 %, 0.78 %, 2.3 %, and 4.0 % respectively, compared with the reference beam.

3.2 Load–deflection behavior

The maximum deflection of all concrete beams presented in Fig. 5b which shows a mid-span load deflection curve. The results show that maximum deflection increases as PET waste content increases in the concrete beams. The reference beam B 0 % had the lowest maximum deflection of 28.4 mm, whereas the concrete beams B 5 %, B 7.5 %, B 10 %, B 12.5 %, and B 15 % recorded maximum deflections of 32.1, 34.1, 35.3, 39.63, and 48.22, respectively, i.e. greater than the reference specimen by 23.2 %, 30.9 %, 35.5 %, 52.1 %, and 85.1 %, respectively. Beam B 20 % achieved the highest maximum deflection of 50.47 mm with an increment of 93.7 % more than the reference beam Fig.10. This behavior somewhat concurs with Kim's conclusion in his study regarding the effect of PET fibers on the structural behavior of concrete beams [10] if the variance in the size, shape, and proportions of PET as well as the difference in the beam dimensions are considered carefully. The behavior of concrete beams through the maximum deflection path shown in Fig. 5b clearly indicates that the presence of PET waste has a positive effect and changes the behavior of concrete beams to another more flexible behaviour Fig. 5c. If the ultimate failure load and the maximum deflection are connected, the sample B 20 % is the optimum. It is also an indication of prolonging the fraction time and providing an early warning before failure. It is a very important characteristic of concrete to reduce the effect of earthquakes and dynamic and impulsive loads.

3.3 Ductility index

Ductility index μ can be obtained from the load–deflection curve, which equals the ratio of ultimate deflection Δu to yield deflection Δy. Ductility index results for all concrete beams are shown in Fig. 5d. The ductility index path was very close to the maximum deflection path, and the ductility increase rates showed a compatibility with the increasing rate of ultimate deflection compared with the reference samples. Ductility index increased with increasing the PET waste percentage in the concrete beams, where beams B 5 %, B 7.5 %, B 10 %, B 12.5 %, B 15 %, and B 20 % recorded ductility indices of 3.21, 3.78, 3.83, 4.40, 5.18, and 5.47, respectively, with increase ratios of 12.13 %, 32.04 %, 34.03 %, 53.82 %, 81.12 %, and 91.37 %, respectively, compared with the reference beam that recorded the lowest ductility index of 2.89. This finding corresponds to Kim's conclusion in his study of the effect of PET fibers on the structural behavior of concrete beams [10] and Adnan's conclusion in the investigation ofthe effect of using plastic box waste as a percentage of fine aggregate on the structural behavior of concrete beams [24].

3.4 Flexural compression strain at failure load

The flexural strain results show that compression strain increases when the PET waste content increases in reinforced concrete beams. Moreover, the strain curves in Fig. 5e show that the compression strains in reference specimen B 0 % C was 0.000197. Beams B 5 %, B 7.5 %, B 10 %, B 12.5 %, B 15 %, and B 20 % recorded strains of 0.001049, 0.001634, 0.001742, 0.001866, 0.002208, and 0.002443, respectively, with increases of 432, 729, 784, 784, 1020, and 1140, respectively, compared with the reference beam. All strain values were within the limits of flexural strain, which should not exceed 0.0035. The load–strain curve for all specimens in Fig. 8b illustrates the difference between the brittle behavior of the reference concrete beams and those containing PET particles.

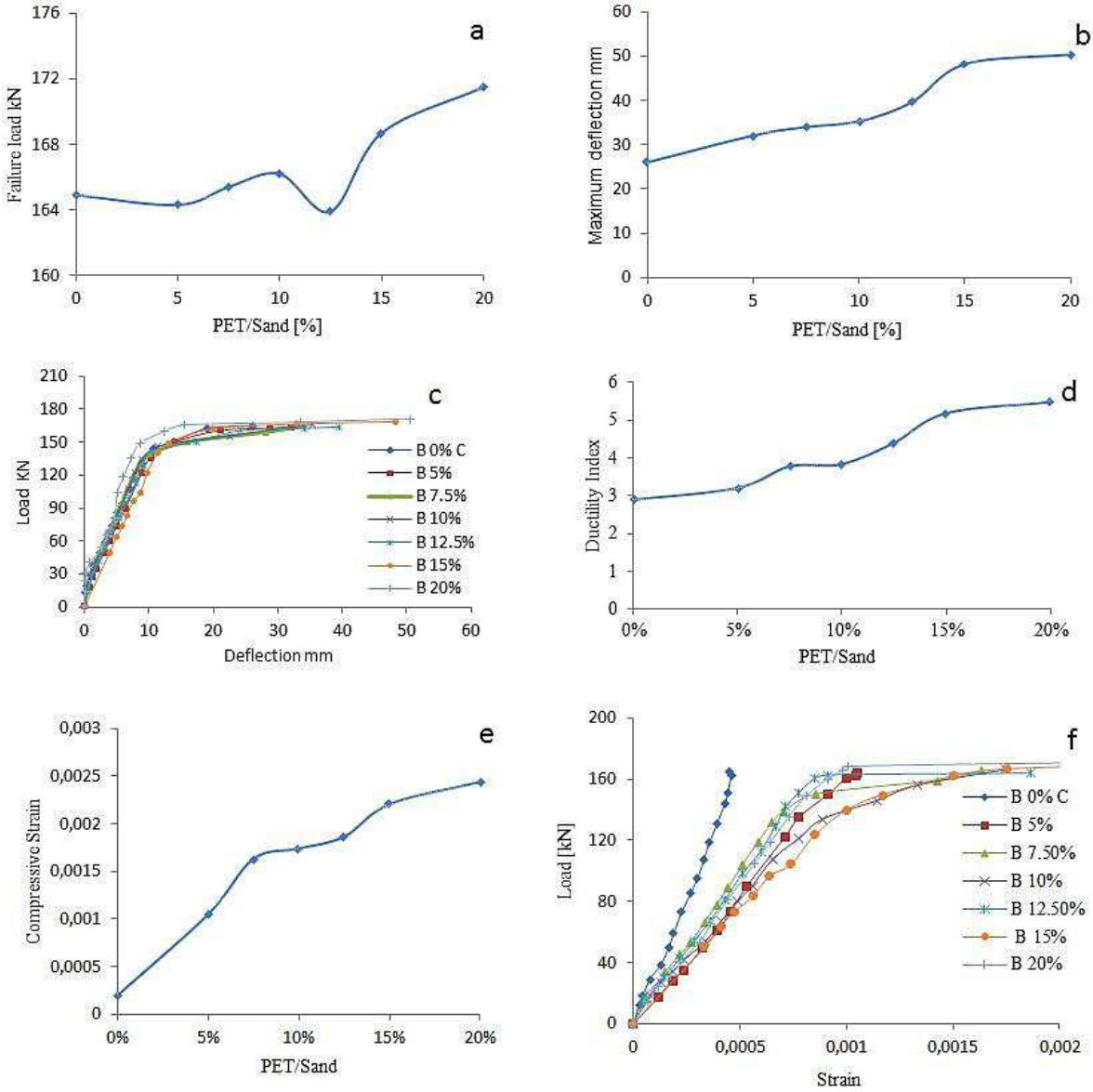


Fig. 5: a) failure load to (PET/sand) relation for all beams; b) load to deflection relation for all beams; c) max deflection to (PET/sand) relation for all beams; d) ductility to (PET/sand) relation for all beams; e) compressive strain to (PET/sand) relation for all beams; f) load to compressive strain relation for all beams relation for all beams.

3.5 Stiffness

Initial and secant stiffness were determined from the load–deflection curve according to previous research [25], as shown in Fig. 11 by dividing ultimate applied load *Pu* either by yield deflection *Dy* in the initial stiffness case or ultimate deflection *Du* in the secant stiffness case. The equations used are shown below:

Initial stiffness = *Py/Dy*, Secant stiffness = *Pu/Du*. (1)

Stiffness calculation was carried out according to [25], as shown in Fig. 6. The results show that the initial stiffness of reference concrete beam B 0 % C or beams with a low content of PET B 5 % and B 7.5 % were close, namely, 35.83, 33.72, and 32.12 kN/mm, respectively. Beams B 10 %, B 12.5 %, and B 15 % recorded initial stiffnesses of 30.21, 28.18, and 25.95 kN/mm respectively, with reductions of 15.67 %, 21.35 %, and 27.56 %, respectively, compared with the reference beam. Beam B 20 % recorded the lowest initial stiffness of 22.05 kN/mm with a reduction of 38.44 % compared with the reference beam. Thus, initial stiffness decreases with the increase of PET waste, as shown in Fig. 7a.

Secant stiffness decreases with increasing the PET waste content in concrete beams, as shown in Fig. 7b. Reference beam B 0 % C recorded a secant stiffness of 6.33 kN/mm. Then, with increasing the PET content in concrete beams, secant stiffness started to decrease gradually, and beams B 5 %, B 7.5 %, B 10 %, B 12.5 %, B 15 %, and B 20 % achieved secant stiffnesses of 5.11, 4.86, 4.70, 4.13, 3.49, and 3.39 kN/mm, respectively, with reduction ratios of 19.27 %, 23.22 %, 25.75 %, 34.75 %, 44.86 %, and 46.44 %, respectively, compared with the reference specimen. Generally, the increase of PET waste content in reinforced concrete beams reduces secant stiffness and initial stiffness. This result is consistent with the results of the deflection in the beams with an inverse relationship between deflection and stiffness.

3.6 Energy absorption

Energy absorption or toughness was computed as the area under the load–deflection curve. The energy absorption results are presented in Fig. 8. The results show a large increase in energy absorption due to the increase of PET waste particles in concrete beams. The reference beam recorded an energy absorption of 339.24 kNmm, whereas concrete beams B 5 %, B 7.5 %, B 10 %, B 12.5 %, B 15 %, and B 20 % achieved energy absorptions of 515.06, 578.6, 623, 785.15, 1154.74, and 1273.6 kNmm, respectively, which were larger than the reference beam by 51.8 %, 70.5 %, 83.6 %, 131.4 %, 240.3 %, and 275.4 %, respectively. This behavior reflects the significant positive effect of PET waste particles on energy absorption in reinforced concrete beams. Energy absorption increased by 4 – 4.8 times compared with the reference samples in the previous study [10] that used PET fibers in concrete beams, whereas it increased 29 times more than the reference beam in the current study. This finding indicates that the energy absorption of the PET particles much exceeds what fiber absorbs.

3.7 Crack investigation

Crack investigation was accomplished according to first cracking load and crack pattern.

3.7.1 First cracking load (pcr) for concrete beam

The first crack loads for all concrete beams were recorded, as presented in Fig. 9. The results show that the load at which the first crack appears gradually increases when the ratio of PET waste in concrete beams increases. The first crack in the reference beam appeared at a load of 18.2 kN, whereas the first crack of beams B 5 %, B 7.5 %, B 10 %, B 12.5 %, B 15 %, and B 20 % appeared at loads of2 8.3, 31.8, 34.2, 35.8, 37.9, and 40.7 kN, respectively, with increases of 53.80 %, 72.8 %, 85.8 %, 94.5 %, 105.9 %, and 121.19 %, respectively, compared with the reference beam. This behavior is consistent with the ductility index results previously shown, which enhances the positive effect of PET waste particles on reinforced concrete beams. In the previous study [9], PET fibers were used in reinforced concrete beams as the use of fibers improves the strength to the first crack by 32 % more than the reference samples. In the current study, this increase was achieved in beam B 7.5 % that contains PET particles as a substitute for sand by 7.5 %, but beam B 20 % that contains a highest percentage of PET particles improved the first crack load by 121 % compared with the reference beam. This finding indicates that the effect of PET particles is higher than the effect of its fibers on the load of the first crack.

3.7.2 Crack pattern

The crack patterns in the beams were variable and appeared in different shapes and lengths. Generally, the cracks appeared at the tension zone midspan and extended till they intersected with compression zone in all beams that contained PET plastic waste with different percentages. Fig. 11 shows the crack pattern of all beams.

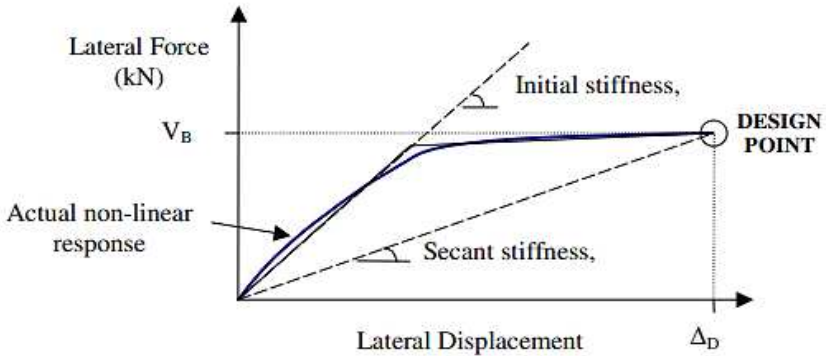


Fig. 6: Initial stiffness and secant stiffness calculation method [25].

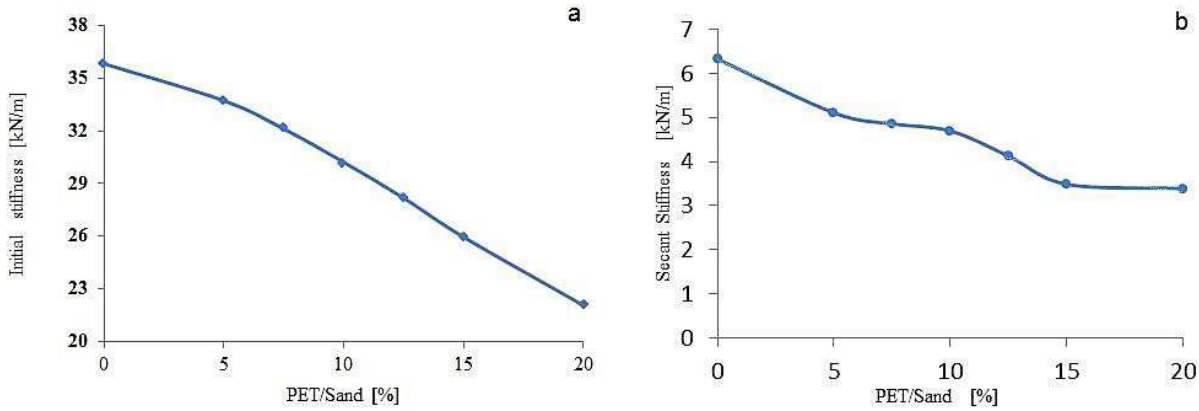


Fig. 7: a) initial stiffness to (PET/sand) relation for all beam specimens, b) secant stiffness to (PET/sand) relation for all beam specimens.

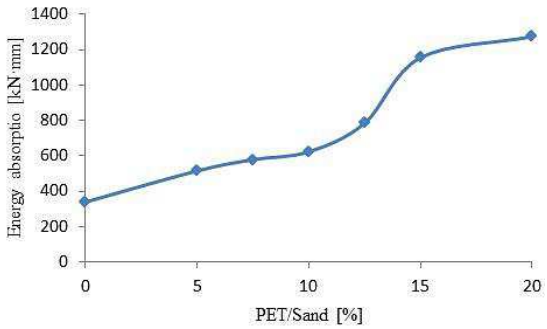


Fig. 8: Energy absorption to (PET/sand) relation curve for beam specimens.

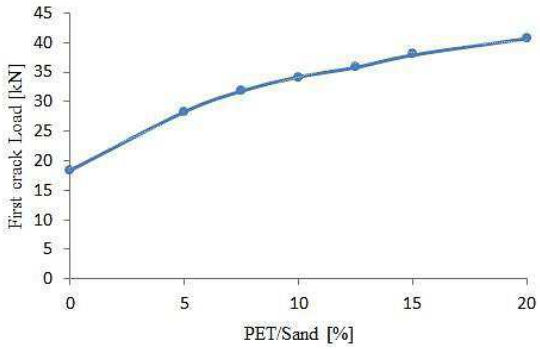


Fig. 9: First crack to (PET/sand) relation curve for all beam specimens.



Fig. 10: Maximum deflection and ductility comparison between the reference concrete beams and the beam containing the highest percentage of PET particles 20 %.

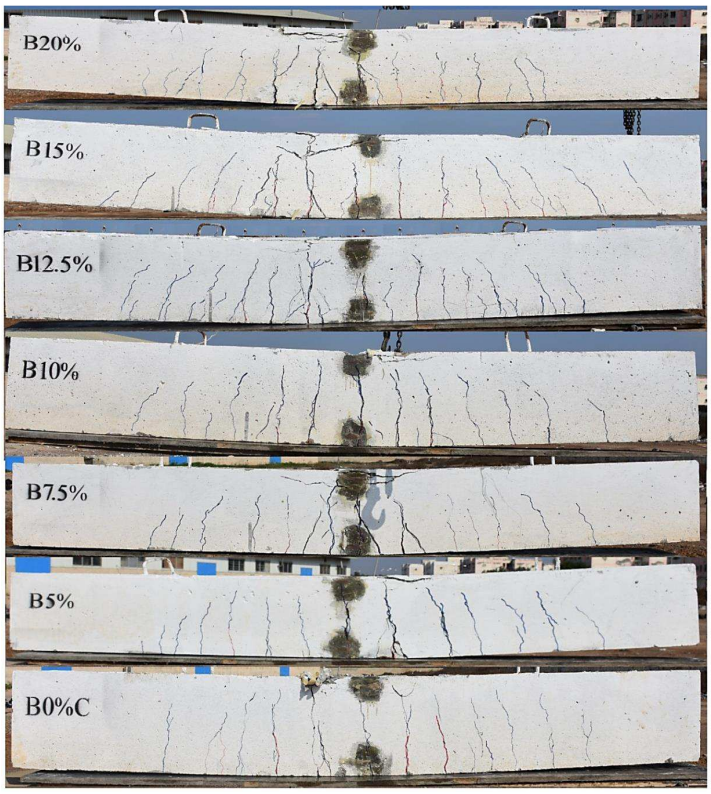


Fig. 11: Crack pattern for all beams.

4 Conclusions

1) The ultimate failure loads of all concrete beams with or without PET were close. Beams B 5 %, B 7.5 %, B 10 %, and B 12.5 % were close to the control beam while beams B 15 % and B 20 % recorded failure load increments of 2.3 % and 4.0 %, respectively, more than reference beam.

2) Maximum deflection and ductility index increased as the content of PET waste in reinforced concrete specimens increased, where beams B 5 %, B 7.5 %, B 10 %, B 12.5 %, B 15 % and B 20 % recorded deflection index increments of 23.2 %, 30.9 %, 35.5 %, 52.1 %, 85.1 %, and 97 %, respectively, and ductility index increments of 12.13 %, 32.04 %, 34.03 %, 53.82 %, 81.12, and 91.37 %, respectively, compared with the control beam.

3) The compression strain at failure load and energy absorption clearly increased with increasing PET replacement percentages in the reinforced concrete beams. Beams B 5 %, B 7.5 %, B 10 %, B 12.5 %, B 15 %, and B 20 % yielded axial strains of 432 %, 729 %, 784 %, 784 %, 1020 %, and 1140 %, respectively, and energy absorption increments greater than that of the control beam by 419 %, 1137 %, 1346 %, 1563 %, 2175 %, and 2749 %, respectively.

4) Initial stiffness and secant stiffness decreased with increasing PET content in concrete beams, where beam B 20 % achieved the lowest initial stiffness and secant stiffness with reductions of 38.4 % and 46.44 %, respectively, less than the reference specimen.

5) The load at which the first crack appeared increased progressively when the PET content in concrete beams increase, where the first crack of beams B 5 %, B 7.5 %, B 10 %, B 12.5 %, B 15 %, and B 20 % appeared at load increments of 53.8 %, 72.8 %, 85.8 %, 94.5 %, 105.9 %, and 121.19 %, respectively, compared with the reference beam.

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