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Behavior of Reinforced Concrete Beam Using Waste Plastic Bottle (PET) Fibers and Recycled Coarse Aggregate

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Abstract: *The deficiency to merge recycled materials in building manufacture is becoming more significant than ever before. The use of recycled materials in concrete mixtures decreases the waste material in landfill and decreases the exhaustion of virgin materials. the basis for this research was to investigate the effects of using recycled materials, in varying amounts, on the fresh and hardened concrete properties. The recycled materials used in this study consisted of Waste Plastic Bottle (PET) Fibers and Recycled Coarse Aggregate. Percentage of the waste PET bottles 0, 1, 2, 3% and recycled coarse aggregate (crashed concrete) 0, 100% from natural coarse aggregate. Fifteen reinforced concrete beams specimens of dimensions (250×120×2000 mm) were prepared in the current research, and divided into five main groups of three beams each, based on % recycled fiber, % recycled concrete coarse aggregate (RCA) and reinforcement steel details (BC, BS, BF). All the specimens of the experimental work were casted and strengthened at concrete research and Material Properties Laboratory, "Faculty of Engineering, Fayoum University". Casting and curing were done according to the Egyptian Code of Practice (2016). The results of the experiments indicated that the use of RCA decrease slump of concrete and this drop of slump was increased by adding PET fiber. the maximum decrease in slump was occurred by adding 3% of PET fiber. the compressive strength was decreased by replacing neutral coarse aggregate with recycled coarse aggregate (crashed concrete by 100%) while the compressive strength increased by adding PET fiber and the optimum increased was occurred by adding 1% of PET fiber. The tensile and flexural strength were decrease also by using RCA and when adding PET fiber, the tensile and flexure strength were increased. The best enhancement of both tensile and flexural strength was at using 3% PET fiber. It was found that using PET fiber enhance the ductility ratio, maximum loading capacity, initial stiffness and toughness of concrete beams. the degree of the enhancement depends on fiber ratio.*

Key Word*: PET fiber; Recycled coarse aggregate RCA; slump; flexural strength; peak load; defection; ductility initial stiffness and toughness; beams.*

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I. Introduction

Countries all over the world suffer from solid waste headache, Solid Waste generation in Egypt has increased to reach the level of 20.5 million tons per year 2010, (SWEEPNET, 2010) [1]. It is projected to reach 35 million tons per year in 2025 (United Nations, 2011) [2]. Demolition waste (DW) and plastic waste (PW) constitute a major portion of total solid waste produced in the world and most of it threw in landfills without any implement.

The most effective way to reduce the solid waste problem is agreed in implementing reuse, recycling it. The application of recycled materials in the building industry is important sustainable development and keeping of primary resources of each country. recycling and reuse of Demolition waste and plastic waste presents interesting possibilities for economizing on waste disposal sites and conserving natural resources.

The idea of adding recycled fiber (RPET bottles fiber) to concrete mixture with recycled concrete aggregate may change properties of concrete, improves its behavior, enable saving resources of natural aggregate and solve apart of solid waste dilemma.

In 2011, Oliveira and Castro-Gomes [3] added PET bottles as fibers to the concrete mixture in different percentages, and the fibers were shredded into 35 mm length at a constant 2 mm width and 0.5 mm thickness. Their results showed that 1.5% of fibers were the optimum percentage for the mix performance. Also, Foti [4] used two forms of polyethylene terephthalate PET fibers (circular and strips). The results demonstrated that these fibers improve the ductility of concrete. Polyethylene terephthalate (PET) fibers and can be used as discrete reinforcement of specimens added to the concrete beams in substitution of steel bars. Three forms of fibers were used; circular fibers, half bottle form to formalize as long PET strips similar to the reinforcement bars in the concrete beams, and the third form was a strip cutting from PET bottles with dimensions (45×0.2×300 mm). By observing the behavior of concrete containing Polyethylene terephthalate (PET) fibers, the researcher reached to the following two conclusions; a high concrete-PET adherence, and a more ductile behavior [5].

In addition, Subramani and Rahman [6] added PET bottle as fibers to the concrete mixture in a percentage of (2, 4, and 6) by volume of the mixture with dimensions (0.6 mm thickness, 5 mm width, and 30 mm length). They observed that 4 % of PET fibers by volume fraction were the optimum percentage for all tests. In 2017, the usage of PET fibers in the manufacturing of the ecological concrete mixture was assessed via optimizing the compressive and tensile mechanical properties [7]. In 2018, Khalid et al. [8] presented a comparative analysis of using different wastes in concrete mixes that included waste wires with length of 55 mm, irregularly shaped polyethylene terephthalate (PET) fibers with size of 10–15 mm, ring shaped polyethylene terephthalate (PET) fibers with widths of 10 and 5 mm, and manufactured synthetic macro-fibers. Furthermore, many researchers focused on using more than one type of plastic waste within the mixture. In 2011, Fraternali et al. [9] used two types of waste; polypropylene (PP) and polyethylene terephthalate (PET) as fibers with different lengths. The compressive strength, thermal conductivity, ductility indices, and first crack strength tests were accomplished. Their results showed that the mixture that contains polyethylene terephthalate (PET) fibers increases the flexural and compressive strength by 22% and 35%, respectively, as compared to both unreinforced concrete and Fibers reinforced concrete. Also, Yesilata et al. [10] used two types of wastes; polyethylene terephthalate (PET) and automobile tire pieces which were added to normal concrete to check heat insulation behaviors of the specimens. The outcomes detected that the suitable addition of the waste into the concrete mixture could improve thermal insulation performance and significantly reduce heat loss.

A cement-based mortar reinforced by PET strips which was acquired through manual cutting of ordinary post-consumer bottles was studied by Fraternali et al. [11]. In 2014, Foti and Paparella [12] utilized PET as discrete reinforcement of concrete slabs in substitution of steel bars. PET strips were arranged as a grid into a slab that was tested for impact load. They reached that the PET reinforcement gave a very ductile behavior to the concrete slabs, which allowed them to avoid complete failure. Mahdi et al. 2013 [13, 14] used PET as a replace of binding material in venue of the commonly utilized ordinary Portland cement to output polymer concrete (PC) and polymer mortar (PM).

II. Research Significance

The main objective set for this research is determined the effect of the different variable percentages of the recycled PET bottles fibers and recycled coarse aggregate (crashed concrete) on the behavior of reinforced concrete beams.

III. Experimental Work

3.1. Materials

3.1.1 Cement

National Ordinary Portland Cement (OPC) was used Type I (BaniSwif). Physical and mechanical tests, complying with Egyptian standard specification, were carried out on a sample of it. The results and the limits of the Egyptian specifications are presented in **Table (1)**.

Table (1): Properties of Used Cement

Property Test	Values	Limits
% Fineness (SieveNo.170)	1 %	Maximum 10 %
Initial Setting Time (min)	82 min	Minimum 45 min
Final Setting Time (min)	225 min	Maximum 600 min
Strength after 3 days(kg/cm^2)	196 kg/cm^2	Minimum 183 kg/cm^2
Strength after 7 days(kg/cm^2)	286 kg/cm^2	Minimum 275 kg/cm^2
Expansion of Cement (mm)	1.5 mm	Maximum 10 mm

3.1.2 PET Fiber

The PET fibers used in this research are a sub product of local Egyptian factory in 6th October city that recycles PET bottles to produce fibers and the evaluated unit weight was 182 kg/m^3 and its specific gravity was 1.11 g/cm^3. The fibers were added to the mortars mixtures as monofilaments with around 0.6 mm diameter and 30 mm length (aspect ratio = 50 (AR50)) shown in **Fig. (1)**.

Fig. (1): PET Fiber

3.1.3 Aggregates

The used fine aggregate in this research was natural sand from 6 October Quarries and coarse aggregate used in this investigation were crushed basalt mix from size number 1 and number 2 from Elmina quarries and RCA were obtained by jaw crusher using 30–40 MPa waste concrete from concrete research and Material Properties Laboratory, "Faculty of Engineering, Fayoum University" as shown in **Fig. (5)**. The basalt and RCA were washed using potable water to ensure the removal of any dust. In step with the Egyptian Standard specifications, they were tested. Properties of basalt, RCA, sand mention in **table (2).**

Type of Test	Value
-Maximum Aggregate Size (mm) for (basalt)	22.4
-Maximum Aggregate Size (mm) for (RCA)	22.4
-Fineness Modulus of Sand	2.31
-Specific Gravity of Coarse Aggregate (basalt)	2.65
-Specific Gravity of Coarse Aggregate (RCA)	2.55
-Specific Gravity of Sand	2.50

Table (2): Properties of Used Aggregate

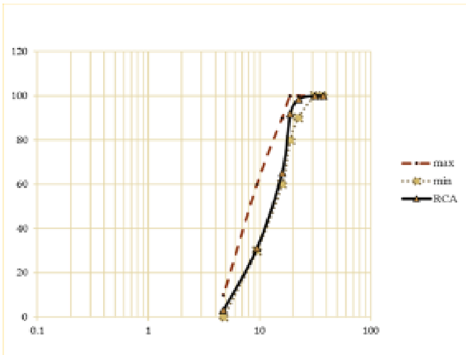


Fig. (2): Results of Sieve Analysis of RCA

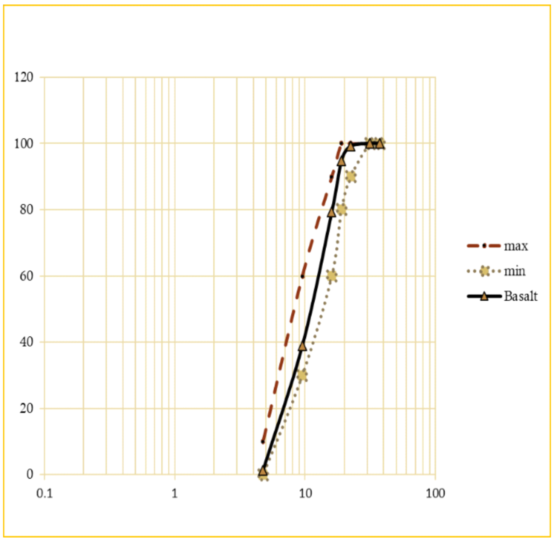


Fig. (3): Results of Sieve Analysis of Sand

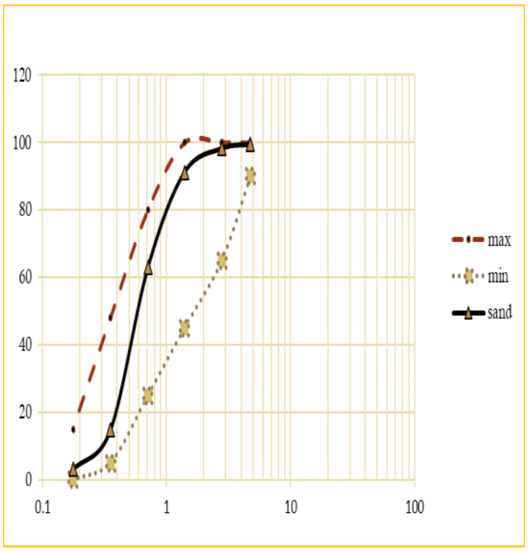


Fig. (4): Results of Sieve Analysis of basalt

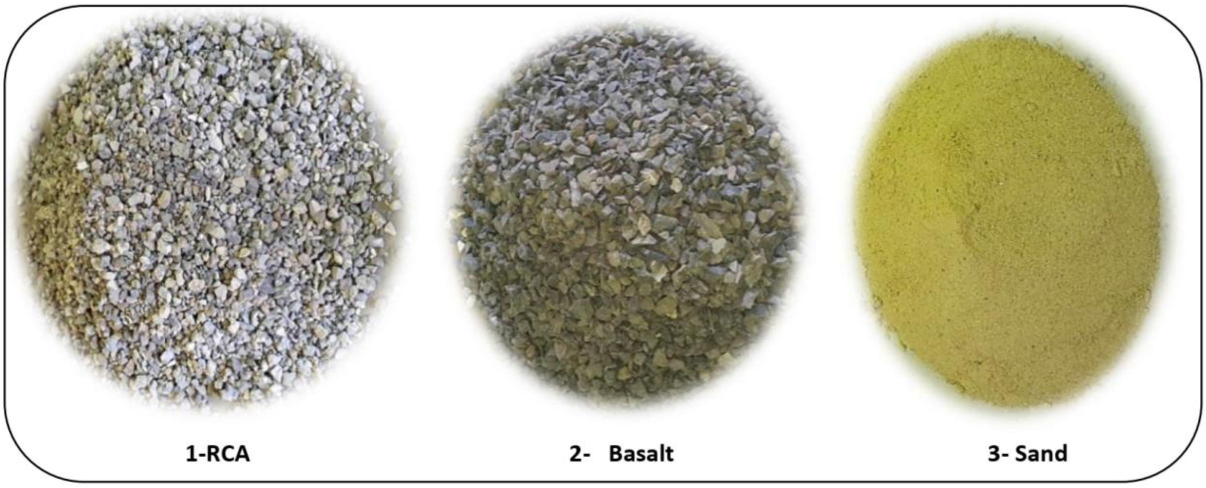


Fig (5): recycled coarse aggregate, basalt and sand

3.2 Mix Design

In this experimental work five mixes were used to inspect concrete beams. The mix design and testing program were conducted in accordance with ECP. The required concrete compressive strength in this research was 25 MPa. Mix proportion by weight (kg/m^3) of fresh concrete is given in **Table (3).**

Table (3): Mix Proportion by Weight (kg/m^3)

Mix	PET fiber	RCA	Basalt	Sand	Cement	Water	Sikament®-NN
Mix 1	0	0	1184	658	350	175	3.5
Mix 2	0	1161	0	645	350	175	3.5
Mix 3	1.82*	1140	0	633	350	175	3.5
Mix 4	3.64*	1124	0	624	350	175	3.5
Mix 5	5.46*	1107	0	615	350	175	3.5

*Percentage of PET x Density of PET.

3.3 Details of Concrete Beams

Fifteen reinforced concrete beams specimens of dimensions (250×120×2000 mm) were prepared in the current research three beams each mix, based on % recycled fiber, % recycled concrete coarse aggregate (RCA) and reinforcement steel details. as shown in **table (4), table (5)**

Table (4): Design of Specimens

	% RCA	%PET Fiber	No of Beam	Specimen Name
Mix1	0%	0%	3	(BC1, BS1, BF1)
Mix2	100%	0%	3	(BC2, BS2, BF2)
Mix3	100%	1%	3	(BC3, BS3, BF3)
Mix3	100%	2%	3	(BC4, BS4, BF4)
Mix5	100%	3%	3	(BC5, BS5, BF5)

Table (5): Reinforcement Details for Beam

Specimen	Beam			
	Span (mm)	Section (mm×mm)	Longitudinal reinforcement	strips
BC	2000	250 × 120	2ϕ10-top 3ϕ12-bottom	10Ø8 /m
BF	2000	250 × 120	2ϕ10-top 2ϕ10-bottom	10Ø8 /m
BS	2000	250 × 120	2ϕ10-top 3ϕ12-bottom	5Ø6 /m

-BC mean control beam strong in flexure and shear**, BF** mean beam weak in flexure**, BS** mean beam weak in shear as shown in figures (6), (7) and (8).

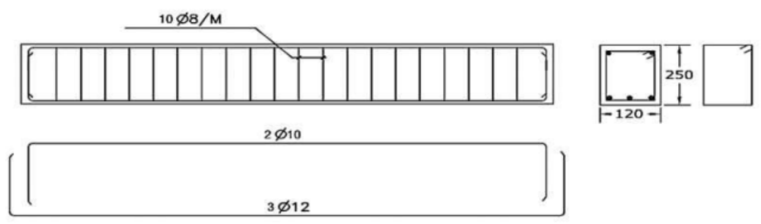


Fig. 6: Reinforcement Details for Control Beam Strong in Flexure and Shear (BC)

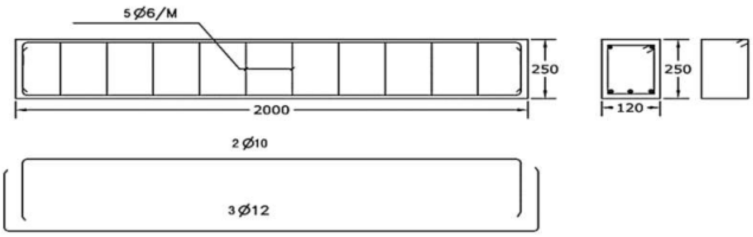


Fig. 7: Reinforcement Details for Beam Weak in Shear (BS)

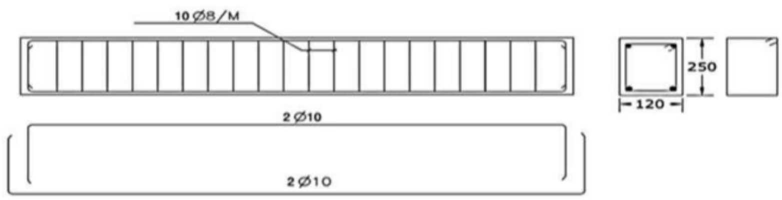


Fig. 8: Reinforcement Details for Beam Weak in Flexure (BF)

3.4 Preparation of Test Specimens

The mixing process started by adding sand to the basalt (or RCA) prior to the PET fibers. These dry components were mixed for about two minutes so that the fibers were evenly distributed throughout the mix. Special care was taken so as to ensure no fiber balls were formed Afterward; cement was added to the concrete mixture. Finally, the water and superplasticizer were added to the mixture gradually. the mixing was continued about 5 minutes so that a good mix was achieved. One of the problems encountered during the mixing was the difficulty of mixing due to the presence of PET fiber which reduces the workability of the mixture. Therefore, the vibrator was used to overcome this obstacle. Six standard cubes (150 × 150 × 150 mm), three standard cylinders (200 × 100 mm), three standard cylinders (30 × 150 mm), three beams (100 × 100×500 mm), were casted from each mix and cured under the same conditions.

Casting and curing of RC Beams specimens: Initially, Horizontal wooden forms were prepared for all beam specimens (120×250×2000 mm) and then, the skeletal reinforcing steel was placed in forms and followed by pouring the fresh concrete in forms as shown. Each specimen was compacted, the surface of concrete was finished smooth using a trowel manually by hand effort. All beams were de-molded after one day and were covered with damp hessian and spraying by water from time to time to keep the humidity during the curing time that finished after 7 days in order to prepare the beams for testing as show in **Fig. 9.**

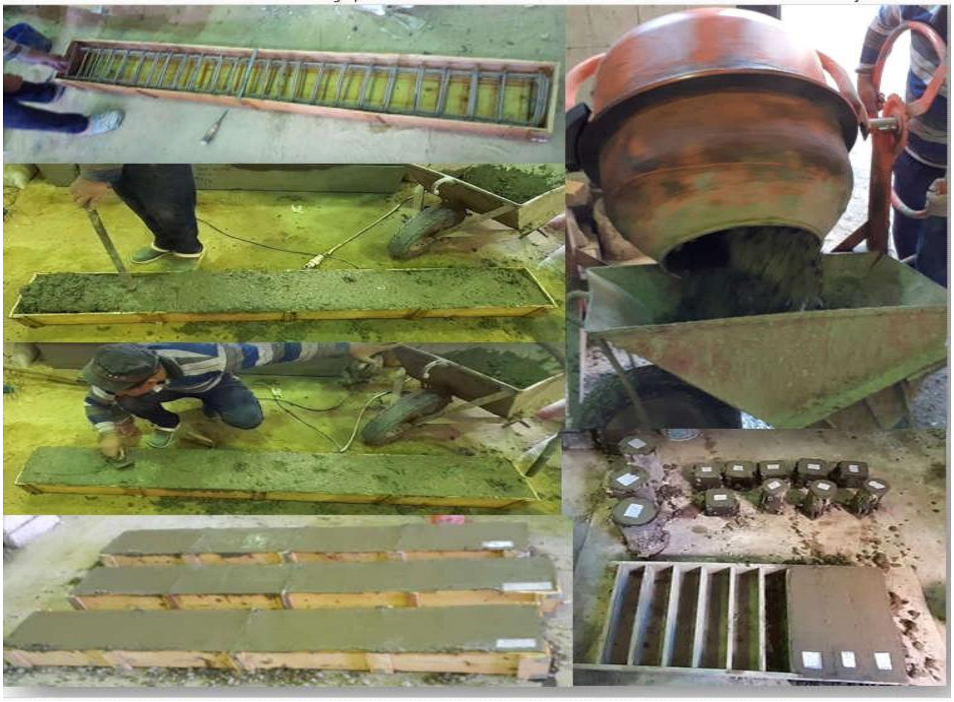


Fig. 9: Preparation of test specimens (Cubic, Cylinders and Beams)

IV. Experimental Results and Discussion

4.1 Fresh Concrete Properties

4.1.1 Slump Test Results

The goal in this section of paper was to find out the effect of polyethylene terephthalate (PET) fibers and RCA on the consistency of the mixture. The results acquired for a slump test for different mixtures were presented in **Table 6 and Fig. 10**. From the results, the slump decreased by using RCA with PET fibers, the slump decreases as PET fibers percentage increased. The reduction of a slump for PET fibers with dosages 0, %1, 2% and 3% are 20%, 50%, 60% and 70%, respectively. The inclusion of PET fiber affects the viscosity of the mix. Fibers interrupt the consistency of the mix. In addition to conventional constituents of concrete, fibers occupy a large proportion of cement paste due to more surface area. The PET fibers obstruct the flow as they form a mesh-like structure adhering to the fine and coarse particles of the mix. This reduces minimum segregation of constituents required to develop the flow of a mix. In addition, the absorption coefficient of recycled aggregates is greater than that of conventional aggregates, which directly affects the reduction of slump.

Table (6): Slump Result

Type of mix	%RCA	% PET fiber	Slump (mm)
Mix 1	0%	0%	100
Mix 2	100%	0%	80
Mix 3	100%	1%	50
Mix 4	100%	2%	40
Mix 5	100%	3%	30

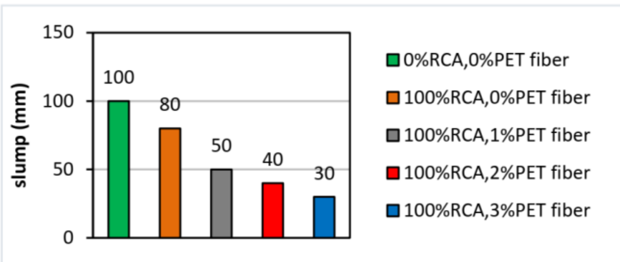


Fig. 10: Slump of Concrete Mixtures

4.2 Hardened Concrete Properties

4.2.1 Compressive Strength Test Results

For each testing age, the average strength of three cubes was registered. Thirty samples de-molded after one day, then cured in a water tank. The averaged compressive strengths of specimens after 7 and 28 days for each mixture are given in **Table 7**. Through checking **Fig. 11** and **Fig. 12**, the compressive strength decreases by using RCA but was increased by adding PET fiber and the maximum increasing in Compressive strength occurred by adding 1% PETF. The increase of compressive strength at 28 days with respect to the plain concrete is equal to 26.7%, 21.4 % and 6.4 % for PET fiber dosages of 1%, 2% and 3%, respectively.

4.2.2 Splitting Tensile Strength Test

Fifteen samples de-molded after one day, then cured in a water tank. The averaged splitting-tensile strengths of specimens after 28 days for each mixture are given in **Table 7**. From **Fig. 13**, splitting-tensile strengths decrease by using RCA but was increased by adding PET fiber and the maximum increasing in splitting-tensile strengths occurred by adding 3% PETF. The increase of compressive strength at 28 days with respect to the plain concrete is equal to 58.6%, 63.1 % and 74.8 % for PET fiber dosages of 1%, 2% and 3%, respectively.

4.2.3 Flexural Strength Test Results

Fifteen samples (100 × 100×500 mm) de-molded after one day, then cured in a water tank. the modulus of rupture of specimens after 28 days for each mixture are given in **Table 7**. The modulus of rupture was decreased by using RCA but was increased by adding PET fiber and the maximum increasing in the modulus of rupture occurred by adding 3% PETF (**Fig. 14**). The increase of modulus of rupture at 28 days with respect to the plain concrete is equal to 67%, 69 % and 74.8% for PET fiber dosages of 1%, 2%, and 3%, respectively.

Table (7): Compressive, Tensile, and Flexural Strength Test Results

mix	% RCA	%PET fiber	Compressive Strength(N/mm^2) 7 days	Compressive Strength(N/mm^2) 28 days	Mean Splitting Tensile Strength (N/mm^2) 28 days	Mean of The Modulus of Rupture Strength (N/mm^2)
Mix1	0%	0%	21	28	2.93	5.16
Mix 2	100%	0%	19.8	25.6	2.53	4.15
Mix 3	100%	1%	3.15	35.5	3.07	8.6
Mix 4	100%	2%	27.2	34	3.13	8.72
Mix 5	100%	3%	26.2	29.8	3.40	9.02

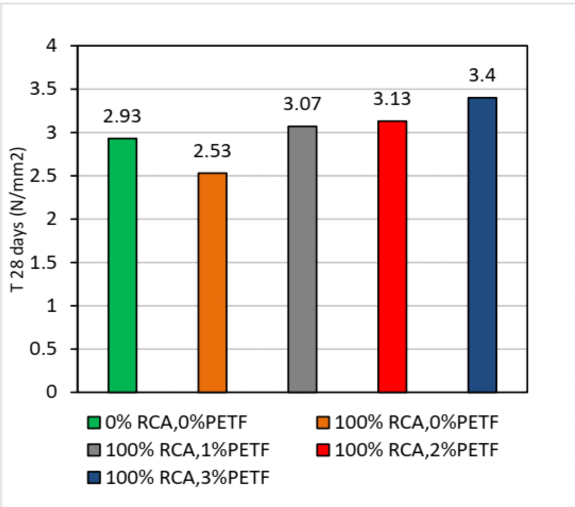


Fig. 13: The Splitting Tensile Test Results

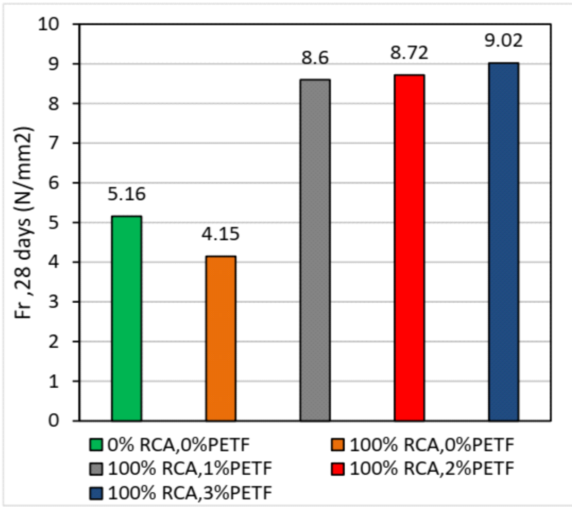


Fig. 14: Flexural Strength Test Results at 28 Days

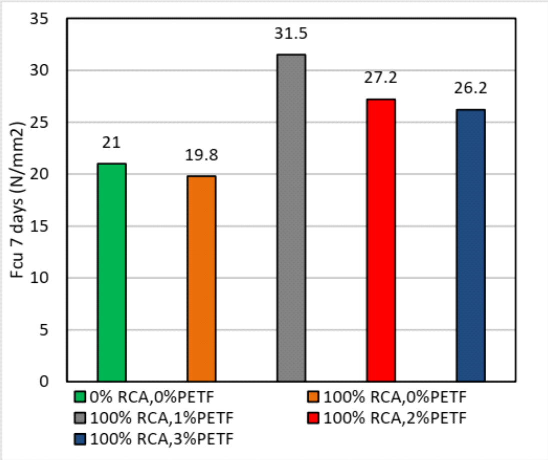


Fig. 11: The Compressive Strength, 7 Days

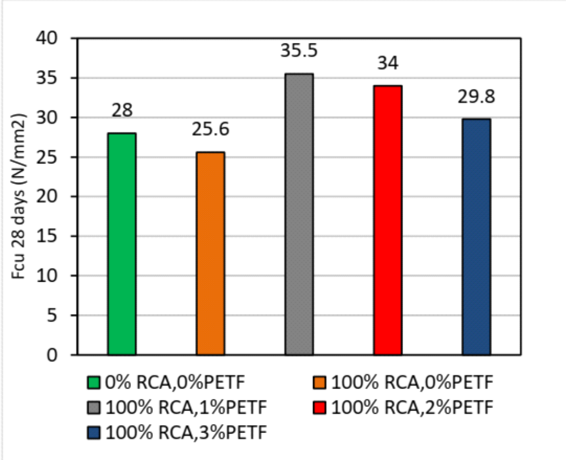


Fig. 12: The Compressive Strength, 28 Days

4.2.4 The Load-Deflection Response

To determine the failure load of beams it is necessary to use loading frame. It consists of three major parts. The main loading frame, which is created from two built- up welded steel section as loading sections as loading frame supports. at the top the- built up loading girder with three loading jacks, which used in loading test. the used loading jack with capacity 200 ton. As shown in **Fig. 15.**

Fig. 15: loading frame machine

The lateral deflection values were recorded versus load values by using LVDT for each specimen**. Fig. 16** shows the load versus the central deflections for specimens BC1, BC2, BC3, BC4 and BC5. It can be seen from the figures that, Peak loads decreased by using RCA but when adding fiber, the Peak load increased. The maximum increasing in load capacity occurred by adding 3% PETF and 100% RCA (BC5).

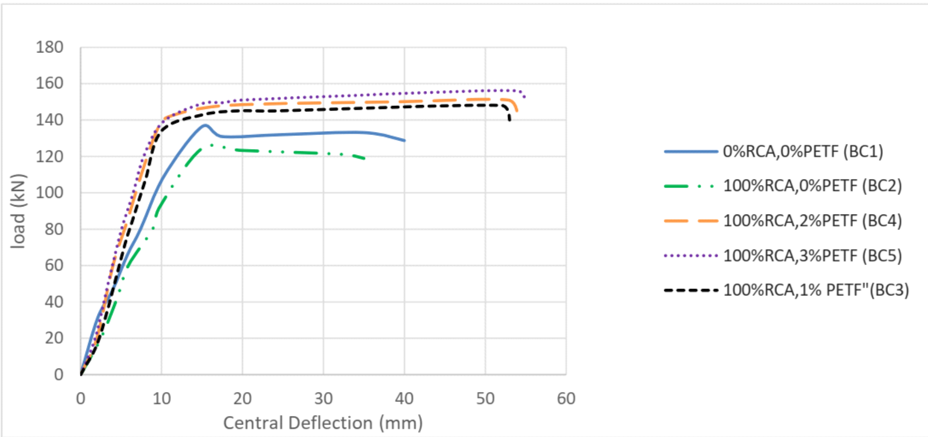


Fig. 16: Load And Deflection Curve for Control Beam

As shown in Fig. 17, it was observed that the control beam of the flexural mode of failure (BF1) experienced minimum deflection at peak load. After the beam was cracked, the deflection continued to rise until the beam reached its maximum load capacity. Similar to the control beam (BF1), The beam (BF2) experienced same deflection but at lower peak load as compare with BF1. The beams with fibers (BF3, BF4, BF5) sustained more load with higher ductility. Besides, the beam (BF5) was achieved higher load capacity that was 21.73% higher as compared to the control beam (BF1) however; the maximum load capacity was reached on a higher deflection.

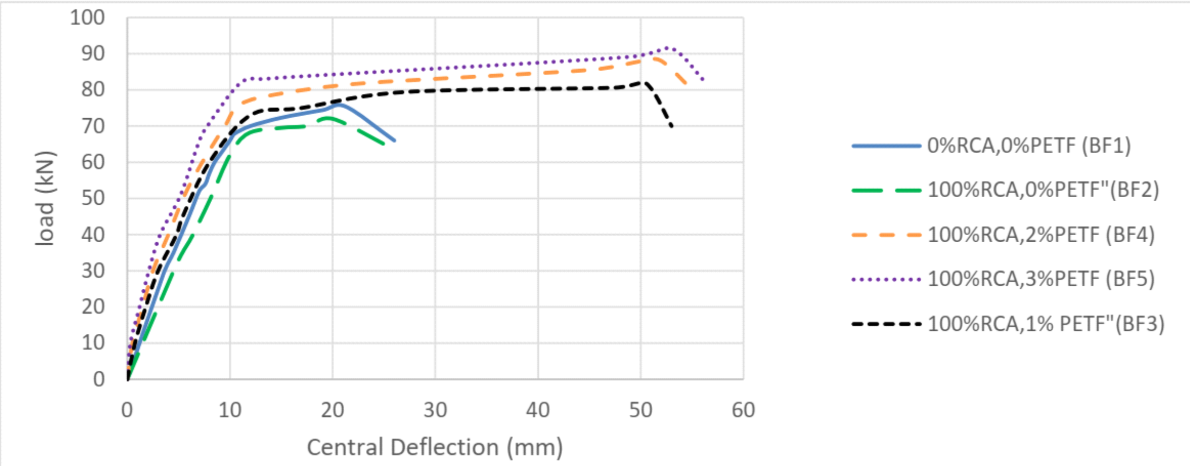


***Fig. 17:** Load And Deflection Curve for week in flexure Beam*

From the results of the load-deflection curve as shown in **Fig. 18** and Table (8), it can be stated that the control beam **(BS1**) failed suddenly after attaining peak load (110 kN) in the pure shear mode of failure. The beam **(BS2)** showed similar behavior as a control beam also showed low deflections before failure but at a lower peak load (80 kN) as compare with the beam **BS1**. The beam **(BS5)** attained a maximum load of (118.00kN). Similar to the control beam **(BS1)** the beam **(BS4)** showed little deflection before failure, but the beam (**BS3)** showed the largest deflection before failure at peak load (117.5 kN). This behavior is because of the random orientation of fibers and not all the fibers can be oriented in the direction to resist the shear failure. Moreover, the short length of fibers was helped control the cracks and thus showed large deflection and more cracks before failure in beam **(BS3).** Thus, it may infer that 1% PET fiber may serve similar to steel stirrup in the PETF beams, which arrested the crack in the shear zone and all cracks disseminated in the pure flexure zone in a ductile manner. **Table 8** summarized the result of the load-deflection response of all beams.

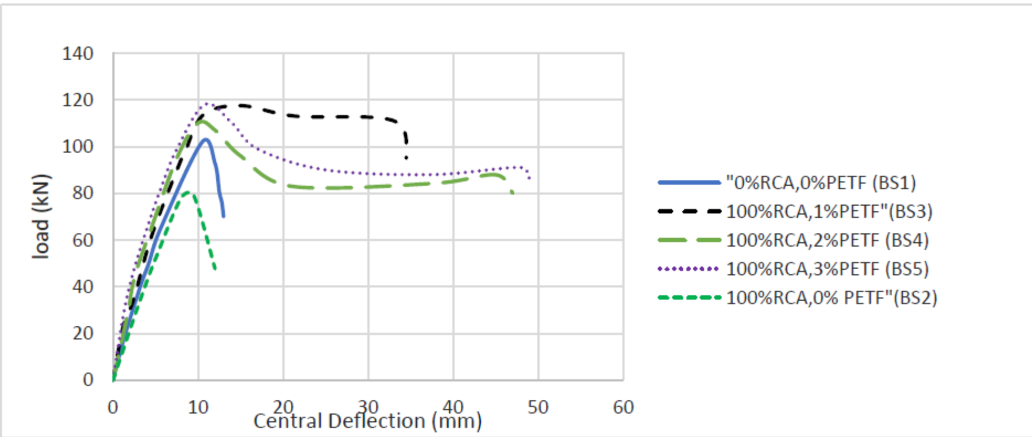


Fig. 18: Load And Deflection Curve for week in shear Beam

Table (8): Result of all beams (the peak load, first crack load, Vu, shear stress, Mcr and Mu for each beam)

Beam No	% RCA	%PET fiber	First crack load(kN)	Peak Load (kN)	Vu (kN)	Ultimate Shear Stress (kN/mm^2)	Mcr kN.m	Mu kN.m	Fru (kN/mm^2)
BC1	0%	0%	107.00	136.5	68.25	4.94	35.67	45.50	36.39
BC2	100%	0%	99.00	124.35	62.17	4.50	33.00	41.45	33.15
BC3	100%	1%	135.00	148.00	74.00	5.36	45.00	49.33	39.45
BC4	100%	2%	137.00	151.00	75.50	5.47	45.67	50.33	40.25
BC5	100%	3%	140.00	156.00	78.00	5.65	46.67	52.00	41.58
BF1	0%	0%	62.00	75.00	37.50	2.72	20.67	25.00	19.99
BF2	100%	0%	60.00	72.00	36.00	2.61	20.00	24.00	19.19
BF3	100%	1%	67.00	81.00	40.50	2.93	22.33	27.00	21.59
BF4	100%	2%	70.00	89.00	44.50	3.22	23.33	29.67	23.72
BF5	100%	3%	75.00	91.30	45.65	3.31	25.00	30.43	24.34
BS1	0%	0%	80.00	110.00	51.00	3.69	26.67	34.00	27.19
BS2	100%	0%	72.00	80.00	40.00	2.90	24.00	26.67	21.32
BS3	100%	1%	83.00	117.50	58.75	4.25	27.67	39.17	31.32
BS4	100%	2%	80.00	110.00	55.00	3.98	26.67	36.67	29.32
BS5	100%	3%	84.00	118.00	59.00	4.27	28.00	39.33	31.45

4.2.5 Ultimate shear strength

The Ultimate shear strength for beams(τ) was calculated by using Eq. (2) that is similar to eq. (4-24) ECP 203-2017 [15]:

$$Vu=\frac{pu}{2} \quad \text{……. Eq (1)}$$

$$(\tau =\frac{vu}{bd}) \quad \text{……. Eq (2) [15]}$$

4.2.5 Ultimate shear strength

Fig. 19 shows the ultimate shear stress of specimens **(BC1, BC2, BC3, BC4 and BC5**). From the figure, it can be stated that the highest value of ultimate shear stress has been achieved by adding 3% PET fiber. The increase of ultimate shear stress with respect to the plain concrete is equal to 8.5%, 10.7 % and 14.4 % for PET fiber dosages of 1%, 2% and 3%, respectively.

Also, ultimate shear stress of specimens **(BF1, BF2, BF3, BF4** and **BF5**) is shown in Fig. 19. It can be seen from Figure that the maximum shear stress of reinforced concrete beams decreased by using RCA without PET fiber, but increase by adding PET fiber. The increase of shear stress with respect to the plain concrete series is equal to 7.7%, 18.38% and 21.69 % for PET fiber dosages of 1%, 2% and 3% respectively

For specimens **(BS1, BS2, BS3, BS4** and **BS5**) it can be seen from **Fig. 19** that, the maximum shear stress of PET fiber reinforced concrete increases for higher fiber dosages., the increase of shear stress with respect to the plain concrete series is equal to 15.19%, 7.8% and 15.68 % for PET fiber dosages of 1%, 2% and 3% respectively**.**

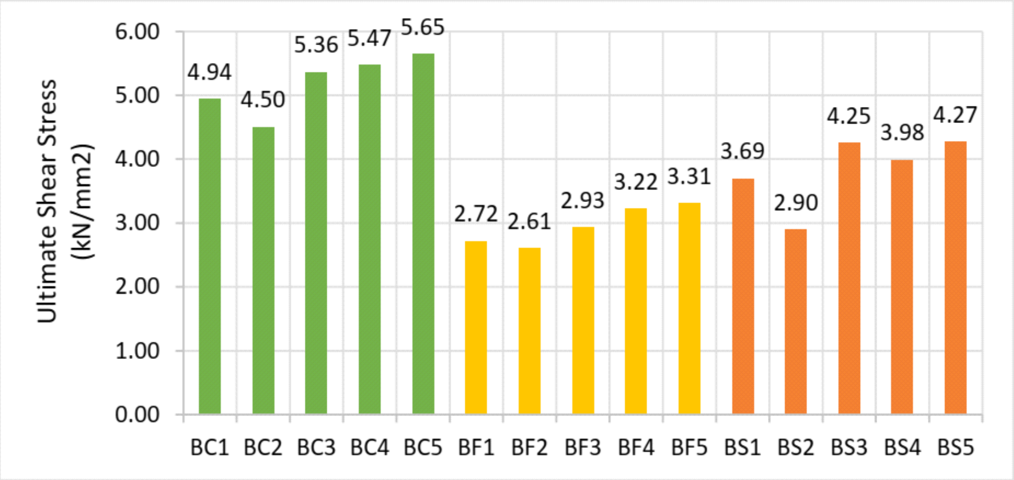


Fig. 19: the ultimate shear stress of all tested beams

4.2.6 Ultimate Flexural strength

The Ultimate shear Flexural strength for beams in **Fig 16** was calculated by using **Eq. (3)** this equation same as eq (24.2.3.5) of ACI318M-19 [16]:

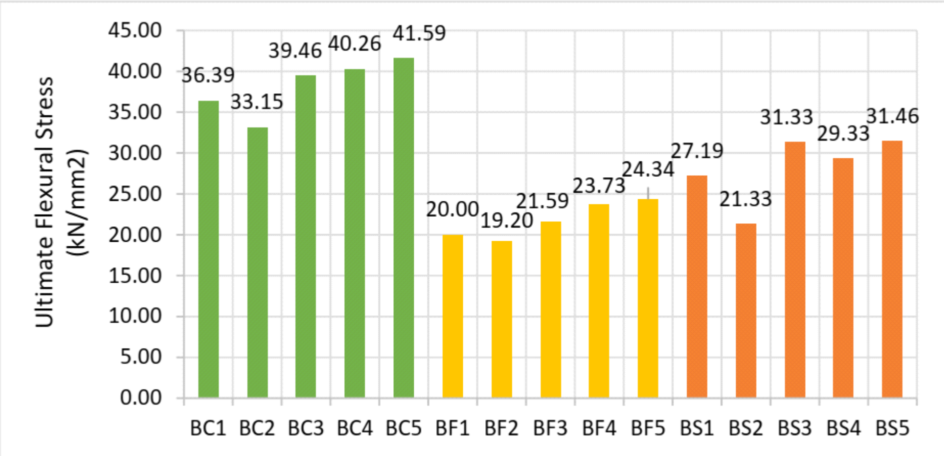
$$Fr = \frac{Mu\,y}{Ig} \quad \text{.... } \textbf{Eq. (3)}[16]$$

in which Mu is ultimate bending moment ($M_u = P_u\ L\ /6$), y equal depth of beam/2, and Ig is the moment of inertia around N.A ($I_g = b\ h^3/12$).

4.2.6 Ultimate Flexural strength

As shown in **Fig. 20** and Table (8)**,** it was observed that ultimate flexural strength was increased by increasing proportion of PET fiber. The optimum increasing in ultimate flexural strength was occurred at percentage 3% of PET fiber. The increase of flexural strength with respect to the plain concrete is equal to 8.4%, 10.6% and 14.3 % for PET fiber dosages of 1%, 2% and 3%, respectively.

The following bar chart in **Fig. 20** explains the relation between adding definite proportion of PET fiber to weak in flexural beams **(BF)** and its influences on the flexural strength. It's so obvious that, when adding 3% proportion of PET fiber has been given the best results. The values of ultimate flexural strength decreased by using RCA without PET fiber, but increased by adding PET fiber with respect to the normal concrete. The increase of flexural strength with respect to the plain concrete is equal to 7.90%, 18.65% and 21.70 % for PET fiber dosages of 1%, 2% and 3%, respectively.



From **Fig. 20**, it can be stated that the ultimate flexural strength decreased by using RCA without PET fiber of weak in shear beams **(BS)**, but increased by adding PET fiber with respect to the normal concrete. The optimum increase at percentage 3% of PET fiber. The increase of results with respect to the plain concrete is equal to 15.22 %, 7.87% and 15.70 % for PET fiber dosages of 1%, 2% and 3% respectively

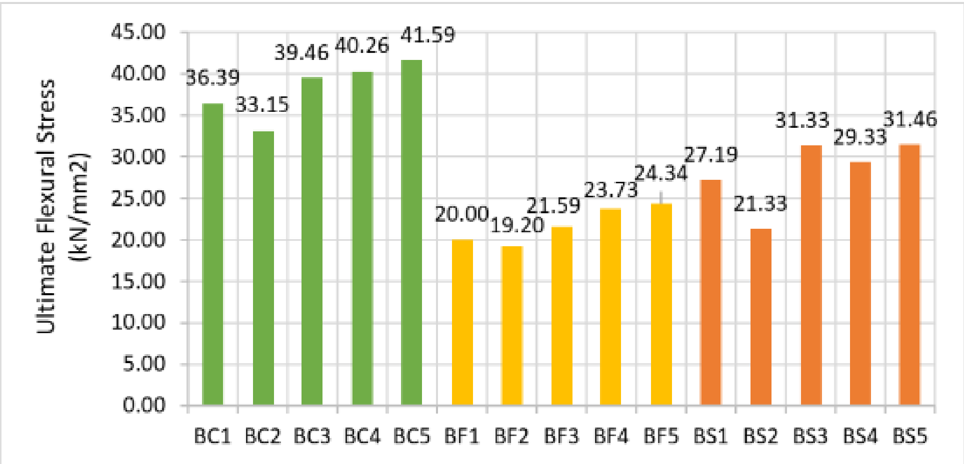


Fig. 20: Ultimate Flexure stress of all beams

4.2.7 Ductility

Ductility is the structural member's capacity to afford inelastic distortions beyond yield distortion without a significant load in its load-carrying capability. The ductility index (i) can be determined from the curve that connects between the load and deflection by dividing the deflection at 0.85 of peak load (Δ 0.85) by yield deflection (Δ y) as shown in the following equation [17]:

Ductility index (i) $= \frac{\Delta.85}{\Delta y}$ ……. Eq (8) [17]

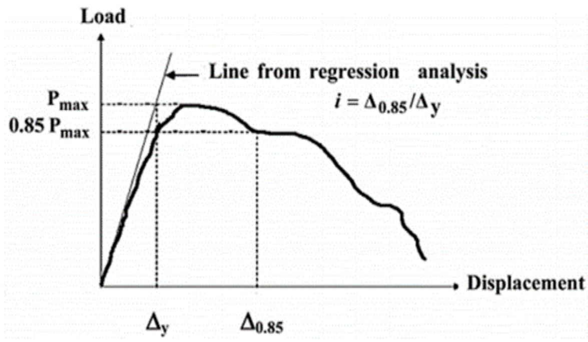


Fig. 21: the calculation procedure of the ductility index

Table (9): Result of all Beams (Deflection, Ductility, Initial Stiffness, Energy Capacity)

Beam No	Δ cr (mm)	Δ u (mm)	Δ y (mm)	Δ0.85 (mm)	Ductility Index (i)	Initial stiffness (kN/mm)	Energy capacity (kN.mm)
BC1	11.00	15.0	13	40.0	3.08	10.50	4438.86
BC2	12.00	15.0	12	35.0	2.89	10.28	3384.10
BC3	12.50	52.0	11	52.0	4.73	13.45	6872.92
BC4	12.75	52.8	10.8	52.8	4.89	13.98	7246.30
BC5	13.00	54.0	10.7	54.0	5.05	14.58	7589.60
BF1	7.00	21.3	10.60	24.3	2.29	7.08	1517.28
BF2	7.20	20.0	11.81	27.0	2.29	6.10	1473.38
BF3	7.40	50.0	10.80	50.0	4.63	7.50	3756.11
BF4	7.90	51.9	10.70	51.9	4.85	8.32	4170.07
BF5	8.10	52.0	10.60	52.0	4.91	8.61	4456.35
BS1	5.00	9.5	9.90	12.5	1.26	10.30	828.94
BS2	7.75	9.8	7.80	10.5	1.35	10.26	604.28
BS3	8.00	15.0	9.80	34.5	3.52	11.99	3284.26
BS4	6.00	9.5	9.00	14.4	1.60	12.22	3873.49
BS5	6.50	11.5	8.60	17.0	1.98	13.72	4291.44

The ductility for all tested concrete beams is presented in **Table 9**. The calculation procedure of the ductility index for each beam is based on **Fig. 21**. As offered in the table 9, the reinforced concrete beams with PET fibers have a relative ductility index of 1.6–5.05. From **Fig. 22** it was observed that the ductility ratio of **(BC) and (BF) beams group** decreased by using RCA without fiber but improved by using PET fibers. The optimum increase occurs by adding a percentage of 3% PET fiber with100% RCA but in the **BS** beam group the optimum increase in ductility occurs by using a percentage of 1% PET fiber with100% RCA.

Notably, the PET fiber concrete beams had the largest ductility index results; this ductility behavior was shown earlier in the load-deflection curve, which reflects the ductility provided by PET fibers. Thus, the inclusion of PET fiber waste with different steel ratio improves the reinforced concrete beam's ductility.

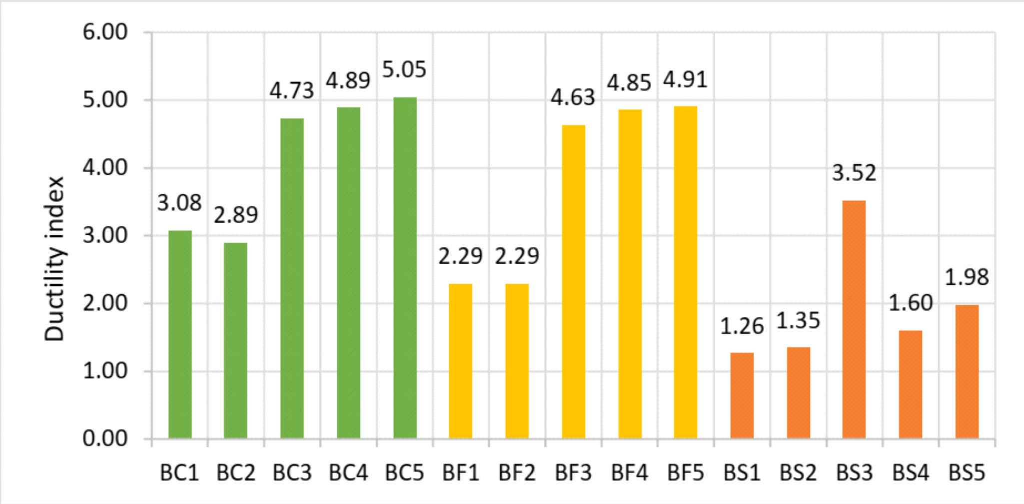


Fig. 22: ductility index results of all beams

4.2.8 Stiffness

In this research, initial stiffness was used to calculate the stiffness of reinforced concrete specimens. The initial stiffness can be calculated from the load-deflection curve by dividing the maximum applied load (Pu) on the yield deflection (Δ y) [18]. Thence, generally, the reinforced concrete beam that has a minimum yield deflection and maximum ultimate load will have a higher stiffness. The equations used are shown below:

Initial stiffness = P_u / Δ y ……... Eq (9) [18]

The stiffness for all reinforced concrete beams was offered in **Table 9**. To clarify the calculation method of the stiffness outputs displayed in the table. As displayed in **Fig. 23**, the results prove that the stiffness of reinforced concrete beams with PET fiber increase as the ratio of PET fibers increases. And initial stiffness decreases by using RCA without fiber.

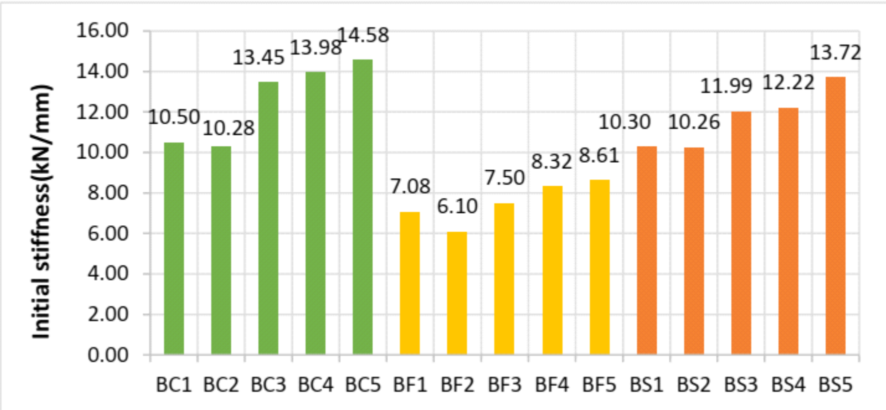


Fig. 23: Initial stiffness results of all beams

4.2.9 Toughness

The toughness is defined as the energy absorption capability of material or structure under load deflection curve up to its failure [19] as shown in **Fig. 24**. In this paper the toughness index was estimated by calculating the area under the load-deformation curve for each beam. The toughness for all tested concrete beams is presented in **Table 9**.

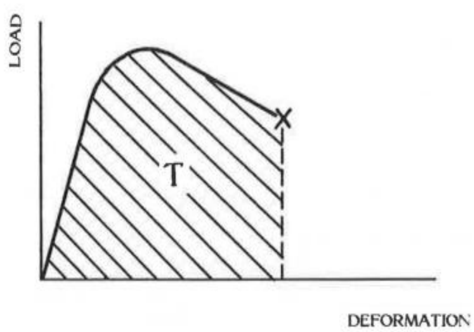


Fig. 24: Definition of toughness.

Fig. 25 shows that the toughness decreased by using RCA without PET fiber but improved by adding PET fiber. The optimum increase occurs at a percentage of 3% PET fiber with100% RCA.

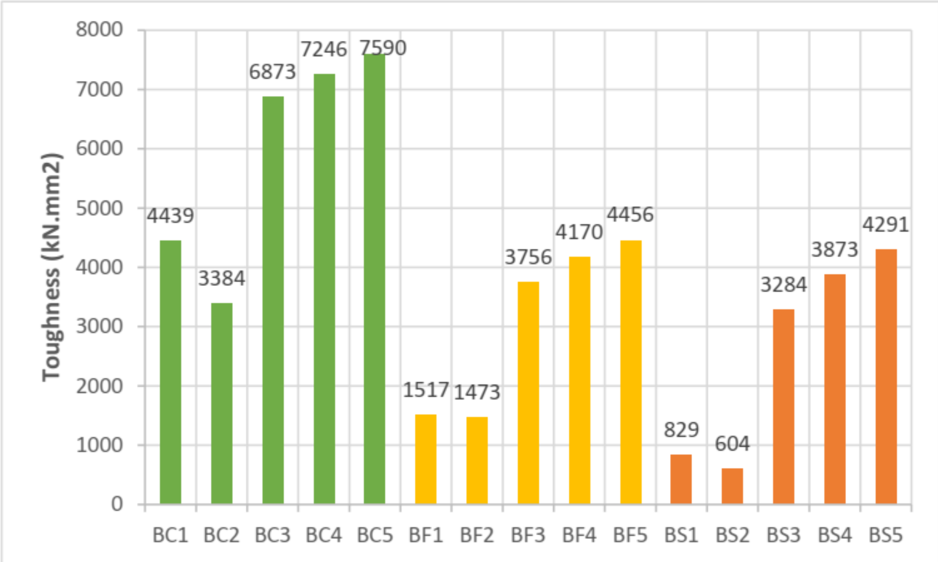


Fig. 25: Toughness results of all beams

4.2.9 Cracking investigation

4.2.9.1 Cracking Pattern and Mode of Failure for control beam (BC)

The crack patterns of all beams at the failure stage are shown in **Fig. 26**. The cracks were concentrated at the mid-span in the beams. In the beam **(BC1)** and **(BC2)** initially, flexural cracks were visible in the constant bending moment zone. The flexural cracks were spread close to the compression zone as the load was increased further. The crushing of concrete was the cause of failure in the compression zone. Similar to the control beam **(BC1)**, the beams in the presence of PET fiber **(BC3, BC4, BC5)** experienced full loading capacity and crushing of concrete in the compression zone. The response of the beam **(BC3, BC4, BC5)** in terms of load capacity and ductility of PET fiber reinforced beams was substantially larger. The spacing of cracks was lesser than the control beam **(BC1)** due to the PET fibers.

Fig. 26: Cracking Pattern and Mode of Failure for control beam (BC)

4.2.9.2 Cracking Pattern and Mode of Failure for weak in flexure beam (BF)

In the beam **(BF1)** initially, flexural cracks were visible in the constant bending moment zone. The flexural cracks were spread in tension zone as the load was increased further. The crushing of concrete was the cause of failure in the compression zone. Similar to the control beam **(BF1)**, the beams with PET fiber **(BF3, BF4, BF5)** experienced full loading capacity and crushing of concrete in the compression zone. The response of the beam **(BF3, BF4, BF5)** in terms of load capacity and ductility of PET fiber reinforced beams was significantly. **Fig. 27** shows the specimens crack pattern after failure. The beams that containing PET fibers show a flexural failure mode and this failure mode evidenced the validity of the previous design that the beams fail in the flexure.

Fig. 27: Cracking Pattern and Mode of Failure for week in flexure beam (BF)

4.2.9.3 Cracking Pattern and Mode of Failure weak in shear beams (BS)

In the beams **(BS1)** and (**BS2)**, Once the load was increased, shear cracks were observed in the constant shear zone and were propagated diagonally in the direction of the loading point. The diagonal tension was the cause of failure. In the beam with PET fibers **(BS3, BS4, BS5)**, hairline cracks started to appear at lower load and a sudden failure occurred through a diagonal tension crack. The specimens exhibit a shear failure mode and this failure mode evidenced the validity of the previous design that the beams fail in the shear except for the beam **(BS3)** which it is failure mode was flexural and shear failure as shown in **Fig. 28**.

Fig. 28: Cracking Pattern and Mode of Failure weak in shear beams (Bs)

V. Conclusions

From the current study, the following conclusions were drawn:

- The workability of fresh concrete decreased by using RCA and this reduction is increased by adding PET fibers with RCA.
- From the hardened concrete tests, the compressive, tensile and flexural strength were decreased by using RCA without PET fiber. While, the incorporation of PET fibers with RCA in the mixture increased the flexural strength and tensile strength and improves the compressive strength.
- The optimum increased in compression strength was occurred by using 1% of PET fiber. However, the optimum increase in the flexural strength and tensile strength was occurred by using 3% of PET fiber.
- The toughness decreased by using RCA without PET fiber but improved by adding PET fiber. The optimum increase occurs at percentage 3% of PET fiber with100% RCA.
- The stiffness of reinforced concrete beams with PET fiber increase as the ratio of PET fibers increases, and initial stiffness was decreased by using RCA without fiber.
- Ultimate flexural and shear strength decreased by using RCA without PET fiber, but increased by adding PET fiber with respect to the normal concrete. The optimum increase at percentage 3% of PET fiber.
- The ductility decreased by using RCA without fiber but improved by using PET fibers.
- The addition of PET fiber reduced the area of spreading cracks in reinforced concrete beams.
- Recycled PET fibers are applicable for fiber reinforced concrete and improve the properties of concrete

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