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Shear strength of a reinforced concrete beam by PET fiber

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Abstract

The shear strength and deformation of reinforced concrete beams have been investigated. For this purpose, an experiment was carried out in the laboratory for the purpose of casting and testing six reinforcement beams, designed to fail in shear, made of concrete containing different PET waste fibers. Direct shear strength of reinforced concrete by PET fiber was also studied via testing six push-off specimens. There is an improvement of the shear capacity of the reinforced concrete beam by 1% PET fiber volume, reached 11.1%. The improvement of direct shear capacity is 43.5% at 1.25% PET fiber volume. Also, the obtained test data demonstrated that adding PET fiber to the concrete beam is capable of changing mode of failure from shear to flexure in concrete beams. Deformations and cracking characteristics of beams and push-off specimens were all modified due to adding PET fiber. Equations have been proposed to calculate direct shear and shear strength of concrete and reinforced concrete beam via adding PET fiber through the usage of the current investigation and available data in Afroz et al. (Int J Sci Eng Technol Res IJSETR 2(9):1668–1672, 2013), Al-Hadithi and Abbas (Iraqi J Civ Eng 12:110–124, 2018), Nibudey et al. (Int J Mod Trends Eng Res IJMTER 02:58–65, 2015) and Prabha and George (Int J N Technol Res IJNTR 3(5):54–56)).

Keywords Concrete beam · Direct shear · Flexure · PET fiber · Push-off specimen

1 Introduction

Polyethylene terephthalate (PET) is widely utilized for industrialized plastic bottles as the container for different food and liquids. Therefore, there are massive quantities of regularly used plastics that lead to huge volumes of wastes and consequently significant ecological difficulties. PET is considered a hard waste material of any city. The plastic waste is a non-biodegradable, so the discard of consumed PET has enormous influences on the ecological contamination (Afroz et al. 2013). As well, the burning of PET bottles leads to emission toxic gasses capable of contaminating the air.

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For the latter periods, researchers have concentrated their experiments in utilizing PET waste in place of normal constituents for manufacturing construction materials of various applications. Researchers Siddique et al. (2008) and Gu and Ozbakkaloglu (2016) have been studied to inspect various properties of concrete with usual aggregates partly substituted with plastic aggregates resulted in plastic wastes. Also, the researchers conducted investigations on the usage of PET waste as fibers in concrete.

Irwan et al. (2014) studied the shapes of the spread cracks in the reinforced concrete beams having fine PET aggregates and exposed to the shear. In this study, ordinary sand was substituted by 25%, 50%, and 75% PET aggregates. They found that used PET aggregate decreases the early cracks resulting from loads to 27%, 38%, and 46% if compared with the equivalent ordinary concrete beam where this PET aggregate influenced the shear strength of the beam, particularly the capability of this beam against shear force via internal roughness and overlapping between aggregates.

Ochi et al. (2007) have studied the advancement of reused PET fibers and their implementation in concrete. They found a technique that can be utilized for getting reinforced concrete by PET fibers. The major anxiety in the increase in usage PET fiber was its resistance to alkali, and there were no difficulties if they were used in ordinary concrete.

Kim et al. (2010) had confirmed the structural assessment of reused PET fiber-strengthened concrete. A technique to reuse waste PET bottles was obtainable, where short fibers were prepared from reused PET and added to concrete. The test outcomes had been revealed that both elastic modulus and compressive strength reduced when the ratio of fiber increased; cracking resulting from drying shrinkage was overdue when concrete specimens contained PET fibers.

Foti (2013) conducted experiments on concrete samplings strengthened by fibers of ring form that cut from the entire PET bottle in ratio 1% of the concrete weight. Two or four overlying strips of bottles were gotten by cutting longitudinally these bottles in two or four parts and then were used for reinforcing two sizes of concrete specimens. The obtained results showed a more ductile behavior for concrete specimens with PET.

Koo et al. (2014) conducted an investigation on reinforced concrete beams by tension and shear rebars and 0.5% of PET fibers and loaded with a four-point loading setup. The vertical deflection and tensile strain were measured; crack beginning and its spread were visually checked and logged through the entire test. The samplings strengthened by PET fiber showed improved better flexural ability than the reference samplings, and these PET fibers could switch off shrinkage cracks and recover the reinforced concrete elements' ductility. These reinforced samplings by PET fiber showed a part of crushing failure in compressive zone followed with yielding of rebar, which was a result of enhanced tensile stress transferring and control of crack in a tensile zone of strengthened concrete beams by PET fibers.

Nibudey et al. (2013a, b, c, d) had been studied the usage of PET fiber in concrete. Two classes of concrete's strength made by utilizing PET fibers of 35 and 50 aspect ratios were investigated. They found that the density, compaction factor, and slump decreases with increasing fiber volume and this decreasing were more when fiber's aspect ratio was bigger. The enhancement in properties of reinforced concrete by PET fiber was higher for 1% fiber volume and 50 aspect ratio.

Afroz et al. (2013) conducted their investigation on the influence of incorporation PET fiber on split tensile and shear strength besides the workability of the concrete mix. They added PET fiber in three ratios of 0.40, 0.46 and 0.52%. Aspect ratio of fiber used was 38 with length 40 mm, width 1.5 mm and 0.6 mm thickness. They found that workability decreased due to the incorporation of fibers at all levels. Splitting tensile strength was increased by 9, 16 and 25%, while shear strength was increased by 30, 70 and 50% when fiber volumes were 0.40%, 0.46%, and 0.52%, respectively.

Marthong and Marthong (2016) investigated the beam-column joint of reinforced concrete by 0.5% and 1.0% PET fibers of 25 aspect ratio. The improvement of loading capacity was in the range of 10–27% by using these fibers. Also, there was development in the ductility and the toughness.

Nibudey et al. (2015) investigated shear transfer strength of two types of concrete via testing push-off specimens. PET fiber volume was added up to 3% at an increment of 0.5%. There was an enhancement in shear strength accompanied by the plastic fiber addition reaching 23% at 1% of PET fiber volume but was found to reduce with increasing PET fiber volume. Shear enhancement was higher for concrete of lower strength and fiber of higher aspect ratio. They proposed two equations for calculating the shear strength of reinforced concrete by PET fiber. Prabha and George (2017) studied the effect of incorporating different PET fibers proportions of 0.5, 1, 1.5 and 2% having different aspect ratios of 4, 8 and 12 on shear strength of concrete beam. They tested ten beams of dimensions 1500×150×100 mm by two central loadings with 1.300 m span. They measured the deflections in the mid-point and loading points. According to their results, shear strength is increased with increasing PET fibers ratio and maximum increase was found to be 36% at 2% PET fiber of aspect ratio equal to 4. When fiber's aspect ratio increased, this load enhancement was decreased. They found the same observation for deflection at the ultimate load. The maximum improvement of deflection was 18% at 2% PET fiber and aspect ratio 4.

Experimental tests on seven 1200×150×100 mm RC beams made of concrete with PET fiber were carried out by Al-Hadithi and Abbas (2018). They used minimum stirrups of 5 mm diameter to get the influence of PET fiber at the shear strength of their beams. (40×4×0.35) mm PET fiber was added by the volume ratios between 0.25 and 1.5%. The shear strength of beams was improved with the presence of PET fiber and converting the mode of shear failure from a sudden to a ductile. The optimum shear strength enhancement was found to be 8.54% accompanied with 1% PET fiber addition. The deflection was decreased by the usage of PET fibers which worked to bridge the cracks.

From the foregoing presentation, it is obvious that there is limited published works on shear strength of reinforced concrete by PET fiber, a limited amount of test data, and consequently, there is a vital need for further researches to be carried out on this topic. Reviewing past works indicate that there is a lack of information about accurate an general design proposal for shear capacity of concrete beam and direct shear strength of concrete reinforced with PET fiber.

The author thinks that there is a need for other experimental data to develop an accurate design proposal for shear design of concrete with PET fiber. The shear strength and deformation of reinforced concrete beams and direct shear behavior of concrete are investigated experimentally. Another part of this study is focused on data analysis to develop equations for shear strength of beams and direct shear strength of concrete reinforced with PET fiber, utilizing test data obtained in this investigation in addition to data from the literature.

2 The methodology

2.1 Used ingredients for mixes

Normal Portland cement (Type I) commercially available was utilized in the mixings of the samples. Tables 1 and 2 display the properties of used cement which conforming to ASTM

Table 1 Chemical composition of cement (current investigation)

Compounds	Abbreviation	% Weight	ASTM C150 specification limits
Lime	CaO	64.43	–
Silica	SiO_2	21.14	–
Alumina	Al_2O_3	5.78	–
Iron oxide	Fe_2O_3	3.59	–
Sulfite	SO_3	2.35	≤ 3%
Magnesia	MgO	1.52	≤ 6%
Loss of ignition	L.O.I	0.89	≤ 3%
Lime saturation factor	L.S.F	0.92	0.66–1.02
Insoluble residue	I.R	0.34	≤ 0.75
Main compounds (using Bogue's equations) (% by weight)			
Tricalcium silicate	C_3S	50.83	–
Dicalcium silicate	C_2S	22.3	–
Tricalcium aluminate	C_3A	9.25	–
Tetracalcium aluminoferrite	C_4AF	10.9	–

Table 2 Physical properties of cement (current investigation)

Physical properties	Test results	ASTM C150 specification limits
Finesse (m^2/kg)	269.5	≥ 260
Initial setting time (min)	3:20	≥ 45 min
Final setting time (h)	4:15	≤ 10 h
Soundness (%)	0.19	≤ 0.8
3 days age compressive strength (MPa)	24.96	≥ 12
7 days age compressive strength (MPa)	30.8	≥ 19

C150 specification bounds (2013a, b). The sand of a clean and dry-saturated surface was used as a fine aggregate, where its the modulus of fineness was 2.98 and its density was 1660 kg/m^3. Grading of fine aggregate obtained from sieve analysis is shown in Fig. 1. One can observe that the actual grading falls within the limits of BS 882 limits (2002) (overall grading).

The coarse aggregate was clean river gravel with a maximum size of 12.5 mm and a dry density of 1686 kg/m^3 in samples' mixing. Figure 2 shows a sieve analysis test of used gravel which conformed to the bounds of BS 882 (2002) (10 mm single sized).

Clean drinkable water was utilized for concrete samples' mixing and their curing. Deformed steel rebar of 6 mm diameter has been used for reinforcing beam and push-off specimens. Figure 3 shows the curve of the stress–strain of steel rebar. Yield stress and ultimate tensile strength of used steel rebar were (395 and 625.3) MPa, respectively, and elongation at fracture was 3.5%.

PET waste fibers cut from 16-L capacity bottles, shown in Fig. 4, were used. PET fibers were cut into the required dimensions from the mentioned plastic bottle excluding the

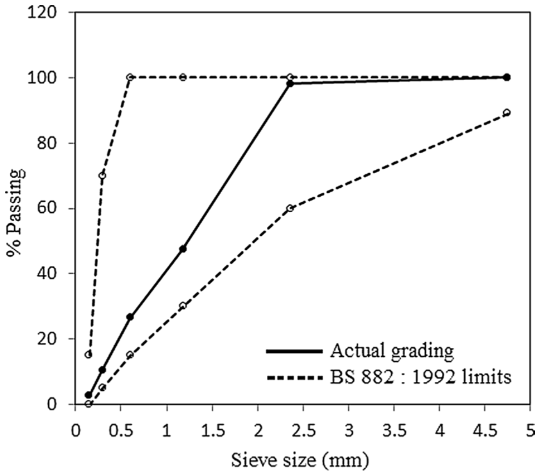


Fig. 1 Grain size distribution of fine aggregate (current investigation)

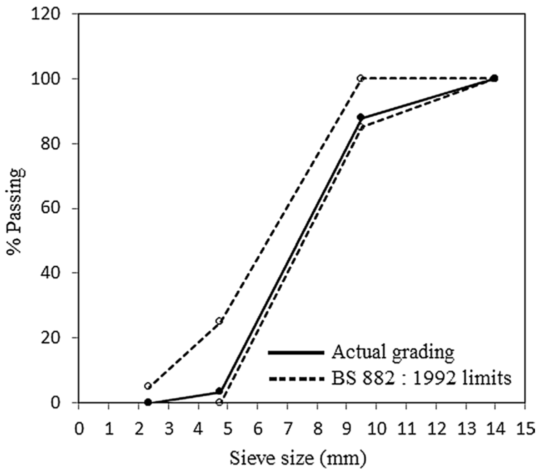


Fig. 2 Grain size distribution of coarse aggregate (current investigation)

neck and bottom by manually using hand scissors. The plastic fiber length was kept to be 25 mm. Average thicknesses and widths of the fiber were measured using micrometer screw gauge. Table 3 shows the properties of the used PET fibers.

2.2 Test program

The test program was arranged to investigate two types of shear strength and deformation: shear strength of reinforced concrete beams made by no reinforcement for shear and the concrete's direct shear strength, all samplings strengthened by plastic fiber obtained from polyethylene terephthalate (PET) bottles waste. For each mix, the compressive strength was measured.

For this purpose, an extensive test program was conducted in the laboratory. Six concrete mixes were prepared, identical except the PET fiber volume. In addition to the

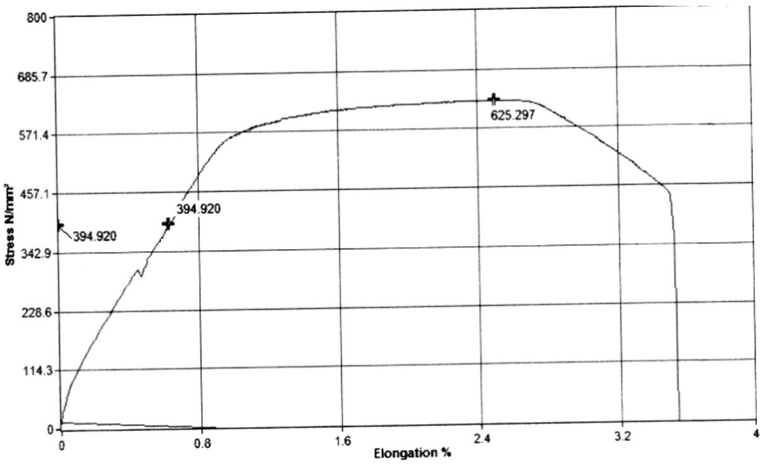


Fig. 3 Tensile stress–strain relationship of steel rebar (current investigation)

Fig. 4 View of PET fiber (current investigation)

Table 3 Average properties of PET fiber used in this study (current investigation)

Property	Results
Fiber length	25 mm
Fiber width	1.5 mm
Fiber thickness	0.37 mm
Tensile strength	126 MPa
Specific gravity	1.24
Aspect ratio	30

control concrete mix, five concrete mixes with PET fiber volumes of 0.5, 0.75, 1, 1.25 and 1.5% were prepared to cast specimens. Accordingly, six beams, six push-off samplings, and eighteen cylinders had been cast and checked.

It is worthy to illustrate the designation used for concrete specimens to be used later for the comparison sake. The symbol B is used for beam, POS is used for push-off specimen, and the number beside the mentioned symbols is the fiber volume. For instance, POS5 is the push-off specimen made of concrete with 1.25% PET fiber volume.

2.3 Specimens' dimensions

Dimensions of concrete beams were 1.10×0.15×0.12 m. Each beam was reinforced with three 6-mm steel rebar in the tension zone for flexure. No shear reinforcement was used, and accordingly the failure of beams could be in shear. An area of flexural reinforcement is moderately greater than the smallest tension reinforcement provided through the code of ACI-318 (2015).

Further details of tested beam can be seen Fig. 5. Steel molds were used for casting beams and push-off specimens (POS), and view of these molds can be seen in Fig. 6. POS was used to investigate the direct shear capacity of reinforced concrete by PET fiber, and for this specimen no shear reinforcement was used in the shear plane. Dimensions and reinforcement details of POS are shown in Fig. 7. For this specimen, shear plane dimensions were kept to be 120×100 mm.

2.4 Concrete mixes

The blend amount for reference concrete was kept to be 1–1.2–2.4 (cement-sand-gravel in weight), and 0.5 of water-cement ratio. A mixer of the volume (0.16 m^3) was utilized for the process of blending in the laboratory at the ambient temperature of 25±1 oC. Before casting, every inward surface of the molds was completely oiled utilizing grease oil. A limited quantity of cement was blended in with aggregates for around one moment. The remaining cement and water were added to the blender, and the materials were left to blend for an additional 3 min. Afterward, the PET fiber was sprayed gradually on the fresh concrete while blending and left to blend for an additional 2 min. The concrete was put in the molds in three layers, each layer exposed to outer vibration. The upper layer of a cast concrete was well leveled by a trowel.

All samplings were detached from molds afterward 1 day of casting. All samplings were cured in the laboratory at room temperature for 4 weeks (see Fig. 8), afterthought removed from the curing tank and put in the laboratory for 7 days to be dehydrated before testing.

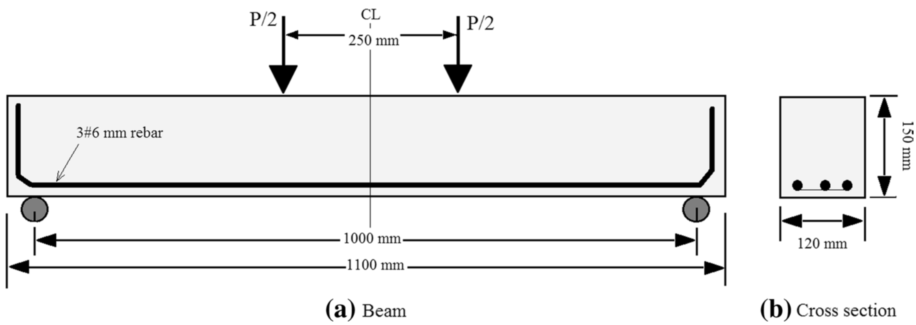


Fig. 5 Dimensions and reinforcement details of tested beams (current investigation), **a** the longitudinal section and **b** the cross-section

Fig. 6 View of molds used for beams and push-off specimens (current investigation)

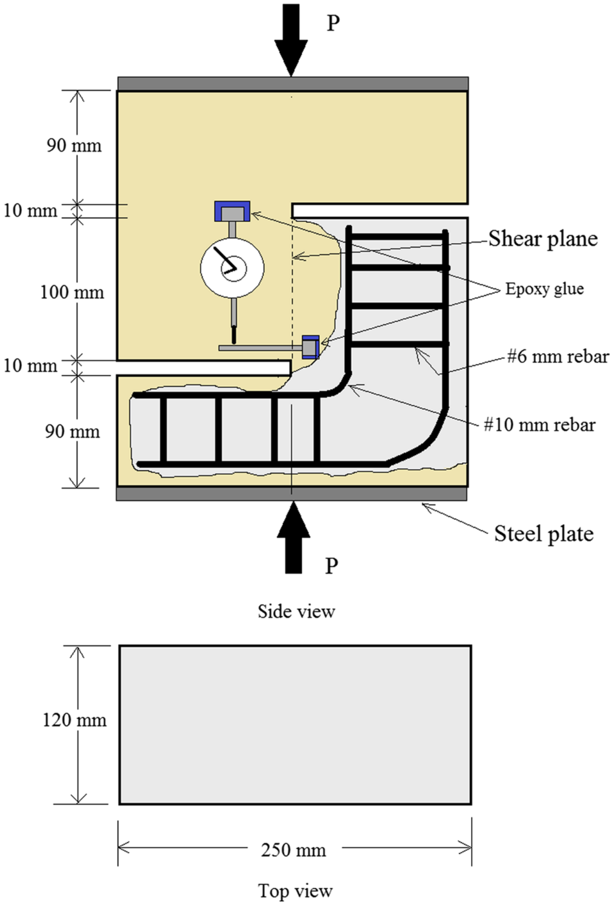


Fig. 7 Dimensions and reinforcement details of push-off specimen (current investigation)

Fig. 8 Specimens inside water tank for curing (current investigation)

Fig. 9 One beam inside the loading frame ready for testing (current investigation)

Side faces of the beams and the push-off samplings were white painted to show cracking extension throughout the applied load. The higher layer of the compression samplings (cylinders) subjected to load was covered by gypsum of great strength to diminish the consequence of stress concentration on samplings surface in contact with the testing machine platens.

2.5 Measurements and instrumentation

A universal testing machine (Test center-Turkey model) shown in Fig. 9 was used to test the samplings' compressive strength (which are 100×200 mm cylinders). For this purpose, the method suggested via ASTM C39 (2013a, b) instructions were followed. The compression sampling was loaded continuously till failure with rate of load 5×10^5 Pa/s. The average of 3 measurements was recorded as a value of concrete's compressive strength. The testing of beams was made using the same mentioned device by two concentrated loads, which were separated by 250 mm, in a span equal to one meter (see Fig. 5). Figure 9 displays a beam prepared for the test. The loads were applied on each beam continuously without shock under loading rate of 5 kN/min till failure. Central deflection of the beam was found by mechanical handle gauge attached at the center of a beam (see Fig. 9).

A push-off specimen was tested in a position shown in Fig. 7. In order to measure the vertical slip which is the differential slip of the two identical L-blocks (see Fig. 7) a dial gage was installed on one concrete block surface using a steel base glued, while on the other block L-shaped small steel arm was glued in order to measure the differential movement of the two blocks. This arrangement is illustrated in Fig. 7. Figure 10 shows one push-off specimen inside the loading frame ready for testing. As for the case of concrete beam testing, the load was applied on the push-off specimen continuously without shock under the rate of 5 kN/min till failure. It should be noted that to catch a relatively large amount of data a digital video recorder was utilized for measuring load and the corresponding deflection.

3 Discussion of results

3.1 Compressive strength

Table 4 displays the values of the compression strength of all samplings. The variant of compressive strength ratio (via usage PET fiber/control) with fiber volume variation is seen in Fig. 11. It finds that a variant of compressive strength is not significant when the different volumes of PET fiber are added. The results are somewhat different from those obtained by Al-Hadithi and Abbas (2018) in which there is a compressive strength enhancement when PET fiber is added to concrete reaching 7.35% at 1% fiber content. This enhancement, however, is not high, and the different between the two results may be due to the difference in the preparation of PET fiber and dimensions. Observation of failure mode and cracking of concrete cylinders indicates that when PET fiber volume in concrete increased,

Fig. 10 One push-off specimen inside the loading frame ready for testing (current investigation)

Table 4 Test results of concrete beams and control cylinders (current investigation)

Beam	V_f (%)	Compressive strength (MPa)	Ultimate load (kN)	Failure mode
B1	0	40.25	34.92	Shear
B2	0.5	37.61	33.56	Flexure
B3	0.75	37.44	28.47	Shear
B4	1	36.08	38.78	Flexure
B5	1.25	36.72	37.57	Flexure + shear
B6	1.5	36.66	35.88	Flexure

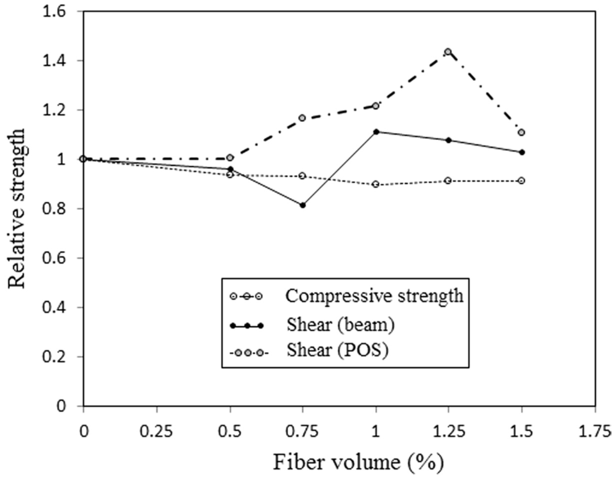


Fig. 11 Variation of different relative strength with PET fiber volume (current investigation)

cracks number, opening and extension are reduced, in which for concrete cylinder with 1.0 and 1.5% fiber no cracks were observed for the failed cylinders in compression. The positive role of PET fiber to control cracking of concrete has been also reported by Ochi, Okubo and Fukui (2007).

3.2 Shear strength and deformation of beams

Table 4 shows the test results of the ultimate load and mode of failure for tested beams. Figure 11 shows relative ultimate load of beams (with PET fiber/control). Figure 12 shows load–central deflection of tested beams. Cracking pattern of beams after failure is shown in Fig. 13. In general, the adding PET fiber to concrete will help to enhance shear strength of concrete beam.

Depending on the results obtained, the effect of such type of plastic fiber for shear strength enhancement is more than that for flexural strength enhancement, because the mode of failure was changed from shear (for beam B1) to flexure (for most of the other beams). Results show that there is some shear force loss of the beam as a result of PET fiber addition up to 0.75% by volume. With increasing plastic fiber volume, there is a load enhancement with an optimum percentage increase equal to 11.1% related to 1% fiber volume. Therefore, in contrast to the case of concrete compressive strength there is a positive effect of the PET fiber addition to enhance shear strength of concrete beams. It is followed

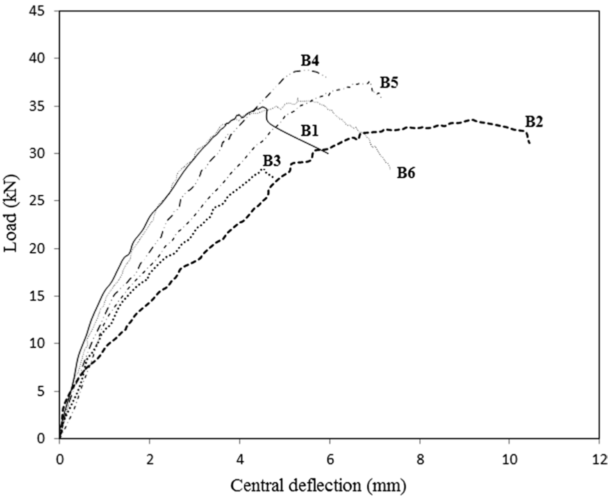


Fig. 12 Load–central deflection relationship of concrete beams (current investigation)

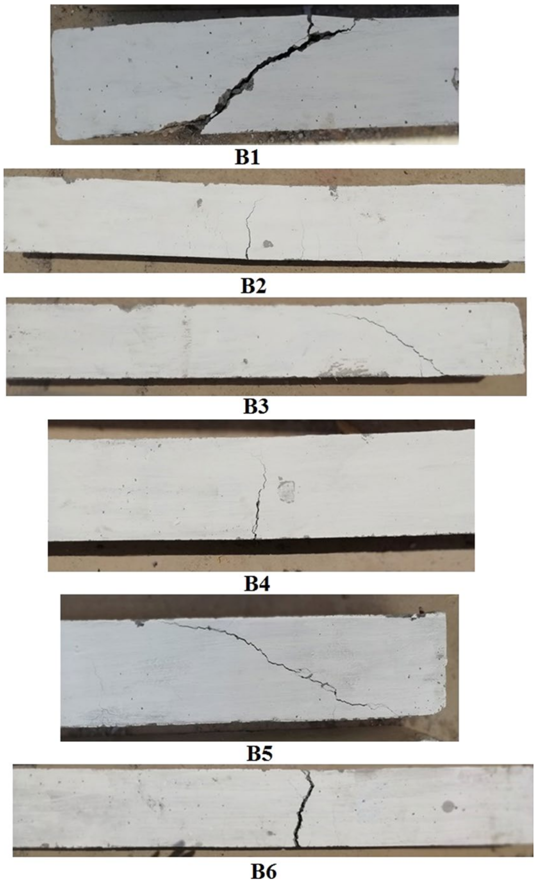


Fig. 13 View of cracked beams after testing (current investigation)

Table 5 Test results of push-off specimens (current investigation)

Beam	V_f (%)	Compressive strength (MPa)	Ultimate load (kN)	Shear strength (MPa)
POS1	0	40.25	51.38	4.28
POS2	0.5	37.61	51.49	4.29
POS3	0.75	37.44	59.79	4.98
POS4	1	36.08	62.40	5.20
POS5	1.25	36.72	73.73	6.14
POS6	1.5	36.66	56.91	4.74

that the action of this kind of plastic fiber is different for concrete subjected to compression as compared with that subjected to shear.

Also, there is no good chance to calculate shear strength of concrete with PET fiber depending on obtained compressive strength values, as it can do for normal concrete, for example, the relation given by ACI 318 code (2015). In general, the mode of failure of beams is the flexural mode or the combination of both flexure and shear. Even in the case of shear failure, it was occurred after the formation of flexural cracks at the center of the beam, essentially different from that of control beam.

Making a comparison between cracking pattern of beams B3 and B5 with that of beam B1 indicates that the width and extension of shear cracks are quite small and are different from that of beam B1 (see Fig. 13). Therefore, besides the shear force enhancement as a result of PET fiber addition, such plastic fiber is able to control cracks extension and further crack formation. Results of load–deflection relationships shown in Fig. 12 indicate that the stiffness of beams denoted by the slope of the initial portion of the load–deflection relationship is slightly reduced when the concrete is reinforced with PET fiber, especially at low fiber contents of 0.5% and 0.75%. Results also show that, in general, there is an increase in deflection corresponding to ultimate load capacity. This behavior may be because of cracking control due to the plastic fiber action in concrete.

3.3 Shear strength and deformation of push-off samplings

Results of ultimate load capacity and direct shear strength of push-off specimens are shown in Table 5, and load–slip relationship is given in Fig. 14. Results show that there is a direct shear strength enhancement as a result of PET fiber addition to concrete, which equals 43.5% at 1.25% fiber volume. This enhancement is relatively high, and therefore, the role of PET fiber to enhance direct shear is more than that of shear capacity of concrete beam.

Based on the obtained test data, PET fiber of 1.25% by volume is the optimum volume for concrete members subjected to direct shear. Results of load–deflection relationship shown in Fig. 14 indicate that the stiffness of concrete in direct shear is moderately increased when PET fiber is added to concrete. Results also indicate that the slip at peck load is enhanced at moderate fiber content but tends to reduce when fiber content is high.

Figure 15 shows cracking pattern of push-off specimens after failure. For the control specimen, there is a high intensity of cracking near the shear plane. As a result of PET fiber addition, such cracks are distributed far from the shear plane, with a relatively wide spacing between them. No cracks were observed for the push-off specimen reinforced with

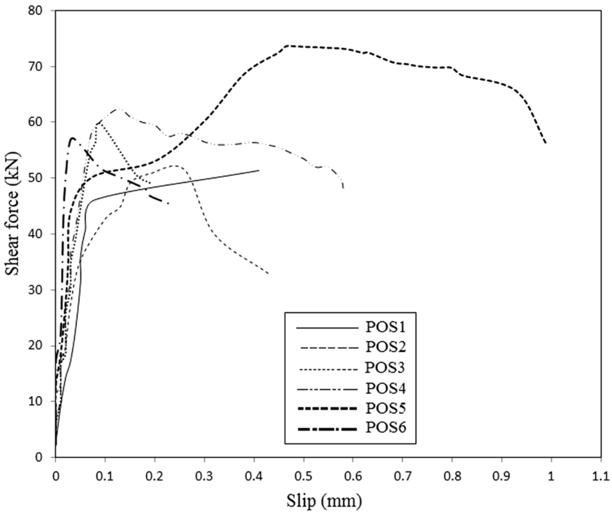


Fig. 14 Shear force–slip relationship of push-off specimens (current investigation)

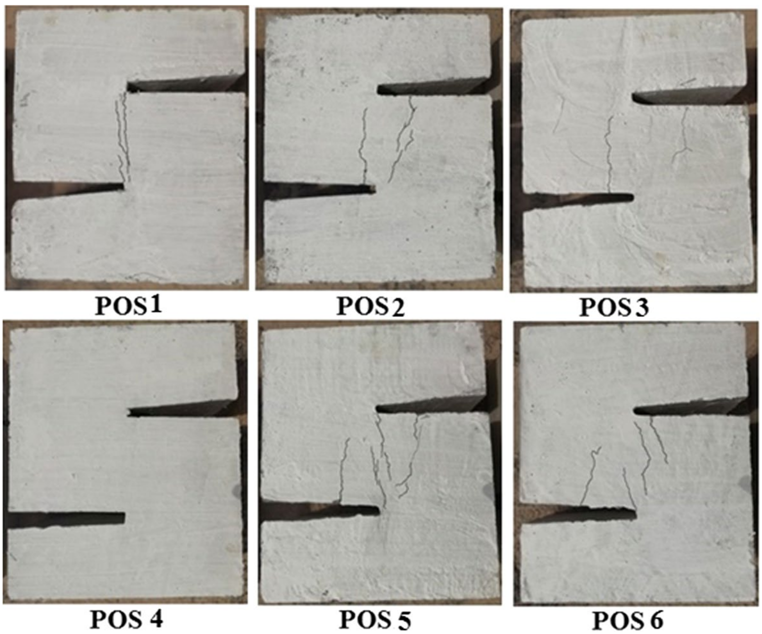


Fig. 15 View of cracks of push-off specimens after failure (current investigation)

1% PET fiber, and in general, one can conclude that PET fiber is able to control cracks produced in concrete subjected to direct shear.

4 Regression analysis on test data

4.1 Shear capacity of concrete beam

There are relatively few amounts of test data on shear strength of reinforced concrete by PET fiber. In contrast to normal concrete without plastic fiber or other kinds of concrete, there is no strong correlation between the shear strength of concrete beam and concrete's compressive strength made by PET fiber. A reason behind this is because of the fact that there is a shear enhancement when concrete contained PET fiber but accompanied no with the compressive strength enhancement.

Therefore, there is a need to investigate other parameters governing shear strength. Here, an attempt was made to collect test data from the literature and combined with the data from this investigation to find a proposal for calculating the shear strength of reinforced concrete beam by PET fiber. In Table 6, a description of test data used for regression analysis is presented. With regard to the test data obtained in this study, those related to 0.75% fiber volume were excluded for regression analysis, because these data are not compatible with others and may not represent the true shear behavior of concrete with PET fiber as compared with the other test data.

Analysis of test data confirmed that highest correlation can be obtained if the dependent variable is taken as the normalized shear strength (concrete with PET fiber/control concrete) (υ_{cf}/υ_c) and the independent variable taken as $V_f d_f/l_f$ where the following variables are illustrated:

υ_{cf} shear strength of concrete with PET fiber,
υ_c shear force of normal concrete,
V_f volume of fibers,
d_f effective diameter of fibers and
l_f length of fibers

Table 6 Description of test data used for regression analysis (1, 2, 9, 16 and current investigation)

References	Fiber volume (V_f)	Aspect ratio (l_f/d_f)	No. of tests data	Shear percentage tolerance
Shear of concrete beam				
Prabha and George (2017)	1, 1.5, 2%	8, 16, 24	10	1.091–1.364
Al-Hadithi and Abbas (2018)	0.25, 0.5, 0.75, 1, 1.25, 1.5%	29.96	7	0.941–1.085
Current investigation	0.5, 0.75, 1, 1.25, 1.5%	29.74	5	0.961–1.111
Direct shear				
Nibudey et al. (2013a, b, c, d, 2015)	0.5, 1, 1.5, 2, 2.5, 3%	35, 50	26	0.837–1.272
Afroz et al. (2013)	0.4, 0.46, 0.52%	38	4	1–1.7
Current investigation	0.5, 0.75, 1, 1.25, 1.5%	29.74	6	1.002–1.435

Considering that plastic waste fiber obtained from cutting bottles has a rectangular cross section, effective fiber diameter can be calculated as follows

$$d_f = \sqrt{\frac{4b_f t_f}{\pi}} \quad (1)$$

where b_f is the fiber width and t_f is the fiber thickness. The variant of normalized shear strength (υ_{cf}/υ_c) with $V_f\, d_f/l_f$ is seen in Fig. 16. Using analysis of regression, the empirical relationship number 2 was found for calculating the shear strength of reinforced concrete beam by PET fiber

$$\upsilon_{cf} = \upsilon_c\left[6.33\left(V_f d_f/l_f\right)^3 - 5.082\left(V_f d_f/l_f\right)^2 + 1.732\left(V_f d_f/l_f\right) + 0.988\right] \quad (2)$$

For relationship number 2, R^2 was found to be 0.77 and can be used for PET fiber volume between 0.25 and 2%.

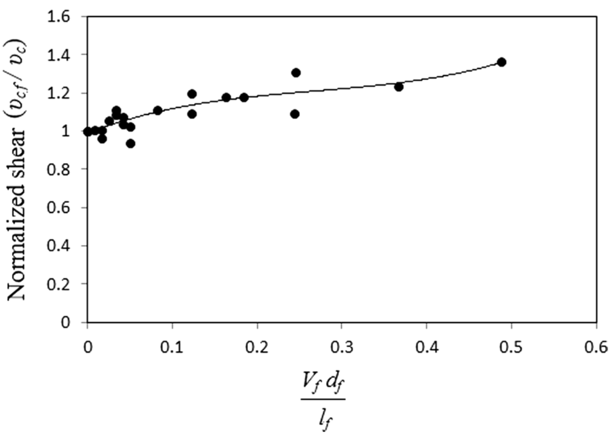
4.2 Direct shear strength of concrete

As a case of concrete beam's shear strength, there is no strong correlation between direct shear strength of reinforced concrete with PET fiber and compressive strength. For reinforced concrete with PET fiber subjected to direct shear, the total amount of test data is greater than that of concrete beam's shear strength. Table 6 contains details of test data used for regression analysis. Figure 17 shows variation of normalized direct shear strength (υ_{cf}/υ_c) with $V_f\, d_f/l_f$. Using regression analysis, the following relationship was obtained for calculating direct shear strength of reinforced concrete by PET fiber

$$\upsilon_{cf} = \upsilon_c\left[4220\left(V_f d_f/l_f\right)^3 - 629.9\left(V_f d_f/l_f\right)^2 + 23.31\left(V_f d_f/l_f\right) + 1.036\right] \quad (3)$$

For the above relationship, R^2 was found to be 0.451 and can be applied for PET fiber volume between 0.4 and 3%. Both Eqs. 2 and 3 can be used to compute the shear strength of reinforced concrete by PET fiber and can be utilized for shear design of concrete beam or concrete members subjected to direct shear. The author recommends carrying out further

Fig. 16 Variation of normalized shear of concrete beam with $V_f\, d_f/l_f$ (1, 2, 9, 16 and current investigation)



researches on this topic and refining a design proposal depending on a great number of experimental results.

5 The concluding remarks

Depending on experimental data and tested data's analysis presented in this paper, the following concluding remarks can be drawn:

1. Adding PET fiber is not useful to enhance compression strength of normal strength concrete, and there is no significant strength loss.
2. There is an enhancement in shear strength of concrete beam designed to fail in shear. Maximum shear enhancement was reached 11.1% related to using 1% PET fiber volume. According to the obtained test data, there is no chance to correlate shear strength of concrete beam with the compressive strength of concrete.
3. The effect of PET fiber to enhance direct shear is more than that of shear strength of concrete beams. Maximum direct shear enhance of 43.5% related to 1.25% fiber volume was obtained. As for the case of concrete beam, there is no chance to correlate direct shear strength of concrete with compressive strength of concrete with PET waste fiber.
4. In general, existence of PET fiber in concrete is accompanied with reduction in number of cracks and their spacing and able to change mode of failure from shear to flexure. Accordingly, the effect of PET fiber to enhance shear is more than flexure.
5. In general, the existence of PET fiber in concrete is accompanied by a reduction in the number of cracks, and at current research, it found cracks are decreased in their numbers and their width where no cracks were detected for the push-off specimen reinforced with 1% PET fiber. In general, there is a limited test data to construct a model for both shear strength of concrete beam and direct shear strength predictions. An attempt was made to develop equations from the analysis of regression on obtainable experimental results. The suggested equations may be used for the shear design of reinforced concrete by PET fiber. The found equation for calculating shear strength of concrete with PET fiber has R2 of 0.77 which can be utilized for the ratio of PET in a range of 0.25–2%.

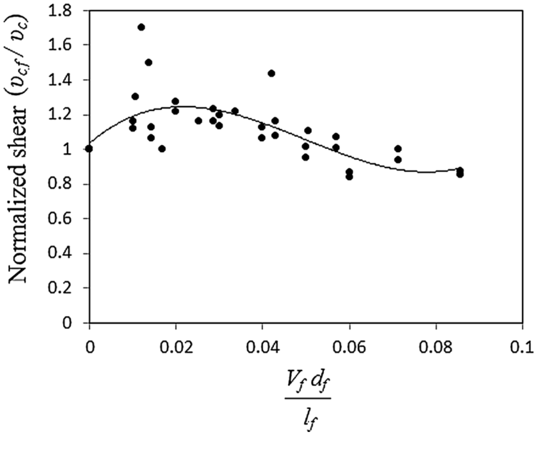


Fig. 17 Variation of normalized direct shear with $V_f\, d_f/l_f$ (1, 2, 9, 16 and current investigation)

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