The Effects of adding Waste Plastic Fibers on the Mechanical Properties and Shear Strength of Reinforced Concrete Beams

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Received: 16 /7/2017 , Accepted: 2/1/2018

Abstract

The concept of sustainability was developed in the last years and included the construction industry to solve the issues that pertaining by high consumption of natural sources, environmental pollution and high amount production of solid wastes. On the other hand, the plastics generation is growing exponentially every year, especially, types of Polyethylene Terephthalate (PET) that are used to produce soft drinks bottles, this study attempts to apply the concept of sustainability and reduce the environmental pollution by cutting the plastic bottles (PET) as small fibers added to the ordinary concrete to improve the shear and tensile strength of reinforced concrete beams. For this purpose, the experimental work was carried out to study the effect of waste plastic fibers (PET) on the shear behavior of seven reinforced concrete beams with dimensions of (100×150×1200) mm that were designed to fail in shear, the fibers percentages that were used in this study are (0.25, 0.5, 0.75, 1, 1.25 and 1.5%). Also, the influence of Polyethylene Terephthalate (PET) fibers on the mechanical properties of concrete was studied such as: workability, compressive strength, splitting tensile strength, static modulus of elasticity and ultrasonic pulse velocity.

Keyword: waste plastic fibers, PET, mechanical properties, shear strength, sustainability.

تأثير ألياف النفايات البلاستيكية على الخواص الميكانيكية للخرسانة و مقاومة القص للعتبات الخرسانية المسلحة

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الخلاصة

تم تطوير مفهوم الأستدامة في السنوات الماضية لتشمل صناعة البناء والتشييد لحل القضايا التي تتعلق بالاستهلاك المرتفع للمصادر الطبيعية والتلوث البيئي وإنتاج كميات عالية من النفايات الصلبة، ومن ناحية أخرى فإن إنتاج البلاستيك يمو بشكل كبير في كل عام، وخاصة أنواع البولي إثيلين تيريفثالات (Polyethylene Terephthalate-PET) التي تستخدم لإنتاج قناني المشروبات الغازية. تحاول هذه الدراسة تطبيق مفهوم الاستدامة للحد من التلوث البيئي عن طريق تقطع قناني المشروبات البلاستيكية على شكل ألياف صغيرة التي تضاف إلى الخرسانة العادية لتحسين مقاومة القص و الشد للعتبات الخرسانة المسلحة، ولتحقيق هذا الغرض، تم إجراء الفحص المختبري لدراسة تأثير ألياف النفايات البلاستيكية (PET) على سلوك القص لسبع عتبات خرسانية مسلحة بأبعاد (١٠٠ × ١٥٠ × ١٢٠٠) ملم صممت لتفشل في القص، وكانت النسب المئوية للألياف التي استخدمت في هذه الدراسة هي (٠,٢٥، ٠,٥، ٠,٧٥، ١، ١,٢٥ و ١,٥٪). كما تم دراسة تأثير ألياف البولي إثيلين تيريفثالات (Polyethylene Terephthalate-PET) على الخواص الميكانيكية للخرسانة مثل قابلية التشغيل، مقاومة الانضغاط، ومقاومة شد الانشطار، معامل المرونة و سرعة الموجات فوق الصوتية.

1. Introduction

Concrete is the main material for most constructions in the field of civil engineering and having naturally sourced ingredients. It is characterized by the possibility of formation in any shape or cross section, it has a good strength to the compressive stresses, in contrast, it is weak against the tensile

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stresses and less resistance to the cracking. For these reasons, the discontinuous (discrete) fibers were used to overcome the problem and this concrete is called **Fiber Reinforced Concrete (FRC)**. The development of (FRC) was significantly in the last years, but the concept of using the fibers for strengthening the construction materials is not new, from the ancient times the straws were used with clay to produce the strong bricks and used the horse hair with the plaster and masonry mortar[1].Fiber reinforced concrete (FRC) is represented as a composite material, thus, the properties of used fibers lead to enhance the weaknesses of the normal concrete such as the tensile strength and impact resistance. In other words, the amount of absorbed energy of fiber reinforced concrete increases from the stage of propagating the cracks until the failure occurs, this means the brittle behavior of concrete changes to the ductile as described in the Figure (1) [1].

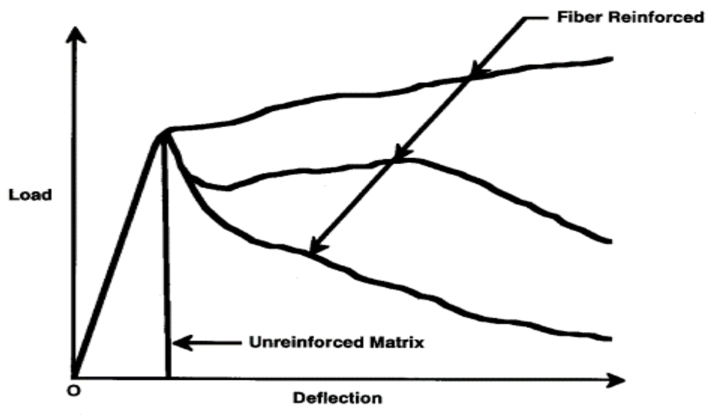

Figure 1. General load-deflection curves of Fiber Reinforced Concrete (FRC) and normal concrete [1]

2. Waste Plastic and Environment

In the recent years, it was observed overstocked large quantities of waste plastic all over the world and the disposal from it requires effort and cost in addition to the environmental pollution by poisonous gases including dioxins as a result of burning various types of plastic. It has become a source of threat to the environment of modern civilization because of the plastic materials are non-biodegradable and containing toxic compounds, especially lead and cadmium, that mixes with the rainwater and pollutes the rivers, seas, oceans and the soil in the case of burial it, also, it needs hundreds of years to return to the cycle of nature [2].

The most common type of the waste plastic is the Polyethylene Terephthalate (PET) products such as bottles of soft-drink, containers for the packaging of food and other consumer goods [3]. The annual consumption of plastic drink bottles was estimated about 10 million tons, according to statistics of 2007, that is equivalent to 250 billion bottles and grows up to 15% every year [4]. The statistics indicate to generation about three hundred million metric tons of waste plastic globally in (2013) only, this value was increased by 4% from the statistics of (2012) that recorded recycling only 9% from the consumer plastic and disregard (32 million tons) [5].

The statistics of **U.S. Environmental Protection Agency (EPA)** [6] for fifty-two years indicated that the rate of recycling plastic disproportionate with the rate of its production, where the plastic production in the year (2012) reached about (31.75) million tons, in contrast, only (2.8) million tons were recovered, which means (9.1%) from the total production of plastic as shown in the Figure (2). Despite the possibility of re-producing the plastic after several steps of treatment operations, it is not economical and the quality of product unacceptable [7].

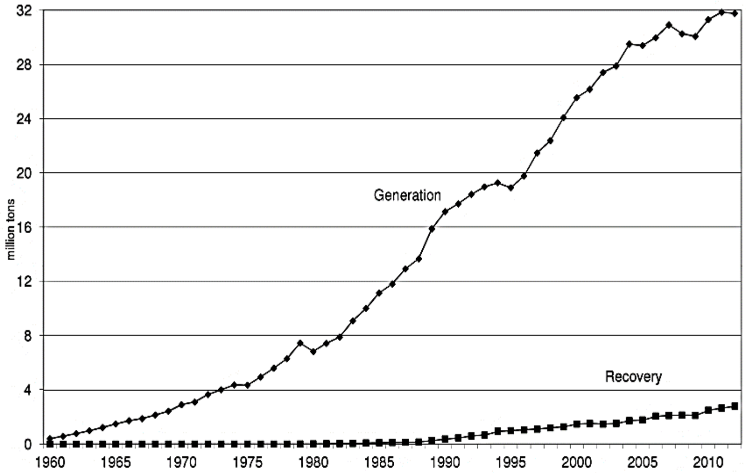

Figure 2. Plastics generation and recovery in United State (since 1960 to 2012) [6]

Also, some researchers studied the possibility of disposing these wastes by advanced ways, such as converting the waste plastic to energy by multiple incineration processes that lead to emissions the toxic gases [8] or convert it to fuel by the methods of pyrolysis [9] but did not indicate to reduce the use of plastic and control on the quantities produced. In addition, some types of plastic can be used for many times without any health risks, but the polyethylene terephthalate (PET) is used for once and after that should be thrown to the waste like soft drink bottles, this will contribute in aggravation of the environmental problems of the accumulation of the solid waste. The best solution to this problem is recycling the waste plastic by using it with other materials to produce materials having properties better than the original condition such as the concrete [10-12].

3. Research Significance

Recently, the use of sustainable materials has been observed in many fields due to the environmental and economic considerations, where the utilizing of recycled plastic fibers certainly an important step towards sustainability. Many structures fail in shear and this type of failure often catastrophic and brittle without sufficient warning before the collapse. As is well known, fibers reinforcement is used to improve the structural performance and mechanical properties of the concrete member, but little is known about the influence of waste plastic fibers on the shear performance of the beam. For this reason, the influence of (PET) fibers on the shear strength of rectangular beams and mechanical properties of concrete are investigated in this study.

4. Materials

4.1 Coarse Aggregate (Gravel)

In this investigation used Al-Nebaee natural crushed gravel with the maximum size passing from the sieve of (14) mm, the gravel cleaned and washed by municipal water several times and allowed to dry in the air. Tables (1) show the physical properties and grading of the coarse aggregate according to the Iraqi standard specification (I.Q.S.) No.45/ 1984 [13] and ASTM C33 specifications (2002) [14], the dry density of coarse aggregate that was used in the experiment is (1650) kg/m^3.

Table 1. Grading test and physical properties of coarse aggregate*

Type of test	Results	The limit of specification according (I.Q.S.) No.45/ 1984 [13]
Grading test		
Sieve size (mm)	% Passing	The limits of cumulative passing (%)
20	100	100
14	97	90 -100
10	74	50 -85
5	8	0 -10
Physical properties		
% of SO_3	0.03%	Not more than 0.1 %
Clay	1%	Not more than 2 %
Specific gravity	2.67	---
Absorption	0.68%	---

* This test was carried out by the Scientific and Engineering Consulting Bureau at University of Technology.

4.2. Fine Aggregate (Sand)

Al-Ukhaidher natural sand was used in the concrete mixes of this study. The grading and physical properties of the fine aggregates conform to the Iraqi standard specification (I.O.S.) No.45/ 1984 [13] and ASTM C33 specifications (2002) [14] as shown in Table (2), the dry density of fine aggregate is (1750) kg/m3.

Table 2. Grading test and physical properties of fine aggregate*

Type of test	Results	The limit of specification according (I.Q.S.) No.45/ 1984[13}			
Grading test					
Sieve size (mm)	% Passing	Zone 1	Zone 2	Zone 3	Zone 4
10	100	100	100	100	100
4.75	93	100 - 90	100 - 90	100 - 85	100 - 95
2.36	71	95 - 60	100 - 75	100 - 85	100 - 95
1.18	52	70 - 30	90 - 55	100 - 75	100 - 90
0.6	30	34 - 15	59 - 35	79 - 60	100 - 80
0.3	13	20 - 5	30 - 8	40 - 12	50 - 15
0.15	3	10 - 0	10 - 0	10 - 0	15 - 0
Physical properties					
% of SO_3	0.3%	Not more than 0.5%			
% Passing 0.075 mm sieve	1.5%	Not more than 5%			
Specific gravity	2.7	---			
Absorption	0.8 %	---			

* This test was carried out by the Scientific and Engineering Consulting Bureau at University of Technology.

4.3 Cement

The ordinary Portland cement that has the trade name (Al-Mas), manufactured in Iraq, was used in this study, the chemical composition and physical properties conform to the Iraqi standard specification (I.O.S.) (No. 5/1984) [15] for the ordinary Portland cement as shown in Tables (3) and (4) respectively, the packaging of cement has a weight of (50 Kg) and was stored in the lab room to avoid the moisture from the air.

Table 3. The chemical properties of ordinary Portland cement*

Item	Test Results	Specification limit [15]
CaO	66.26	---
Fe_2O_3	3.73	---
SiO_2	19.11	---
Al_2O_3	6.42	---
MgO	1.45	Not more than 5 %
SO_3	2.31	Not more than 2.5 %
C_3A	2.9	Less or equal 3.5 %
C_2S	8.52	---
C_3S	61.8	---
C_4AF	7.07	--
Lime saturation factor	0.91	0.66 – 1.02
Loss on ignition	2.2	Not more than 4 %
Insoluble residue	0.96	Not more than 1.5 %

* This test was carried out by the Scientific and Engineering Consulting Bureau at University of Technology.

Table 4. The physical properties of ordinary Portland cement*

Type of test	Test Results	Specification limit [15]
Initial settling time (minutes)	194 min.	Not less than 45 min.
Final settling time (minutes)	245 min.	Not more than 10 h. (375 min.)
Fineness (cm^2/gm) by Blaine method	2600	Not less than 2500
Compressive Strength at 3 days (MPa)	16	Not less than 15 (MPa)
Compressive Strength at 7 days (MPa)	28	Not less than 23 (MPa)

* This test was carried out by the Scientific and Engineering Consulting Bureau at University of Technology.

4.4 Water Mixing

The municipal water was used in the works of casting all specimens and in the process of curing.

4.5 Steel Reinforcement

All beams were reinforced by Ukrainian deformed bars with diameter (Ø16) mm for longitudinal reinforcement and (Ø5) mm for transverse reinforcement (stirrups) as shown in the Plate (1), the properties of steel reinforcement illustrated in the Table (5).

Plate 1. Reinforcing cage

Table 5. Properties of steel bars

Size of bar (mm)	Yield stress (MPa)	Ultimate stress (MPa)
16	657	745
5	431	517

4.6 Waste Plastic Fibers (PET- Fibers)

The (PET) fibers were obtained from cutting the bottles of soft drink as rectangular pieces by using a paper shredder with the net length of (40) mm, average width of (4) mm and thickness of (0.35) mm as shown in the Plate (2). The volumetric percentages of (PET) fibers that were used in this study are (0.25, 0.5, 0.75, 1, 1.25 and 1.5%), the physical properties of fibers illustrate in the Table (6).

a) The paper shredder that was used for cutting the plastic bottles.
b) Cutting the base and upper part of plastic bottles.
c) Waste plastic fibers.

Plate 2. Production of waste plastic fibers

Table 6. Physical properties of waste plastic fibers

Dimensions (mm)	Elongation (%)	Aspect Ratio	Density (Kg/m3)	Water Absorption	Color
40×4×0.35	16	30	1.38	0.00	Crystalline green

5. Mix Design

Four trial mixes were prepared in this experiment as an attempt to get on the perfect mixture with good workability and compressive strength equal to (35) MPa at 28 days. The mix proportions of the chosen mixture are (1: 1.62: 2.55) by weight, where the cement content and the water cement ratio (W/C) are 430 kg/m^3 and (0.448) respectively.

6. Shear Strength

The important part in concrete structures is the beam, it transfers the loads to the supports or columns. The shear failure of reinforced concrete beams occurs abruptly without sufficient warning unlike the flexural failure, also, the width of shear cracks is larger than the flexural cracks [16]. Usually, the flexural calculation is considered the first step in designing the reinforced concrete beams that specifies the dimensions of cross section and the area of longitudinal reinforcement to resist the moments and ensure the ductile type of failure. In shear design, the shear strength should exceed the flexural strength for every beam in the structure by increasing the ratio of vertical reinforcement or search for ways that contribute to increase the shear strength of the beam to reduce the seriousness of the sudden shear failure.

The design of rectangular beams against shear forces according to (**ACI 318-14**) [17] based on, the nominal shear strength (V_n) must be larger than the ultimate shear force (V_u) which is represented by:

$$\emptyset V_n \geq V_u \tag{1}$$

Where: ($\emptyset$) is the strength reduction factor equal to (0.75).

While the nominal shear strength (V_n) is represented by the following relationship:

$$V_n = V_c + V_s \tag{2}$$

V_c**:** The nominal shear strength provided by the concrete that is computed by [17]:

$$V_c = [0.16\sqrt{fc`} + 17\,\rho_w\,V_u d/M_u]\,b_w d/7 \quad \leq 0.29\sqrt{fc`}\,b_w d \tag{3}$$

Or;

$$V_c = \sqrt{fc`}\,b_w d/6 \tag{4}$$

V_s**:** The nominal shear strength provided by steel stirrups that is computed by:

$$V_s = A_v f_{yv} d/S \tag{5}$$

Where:

A_v : area of shear reinforcement (mm^2).

f_{yv} : yield stress of shear reinforcement (MPa).

d : depth of longitudinal steel reinforcement (mm).

S : spacing of shear reinforcement (mm).

From equation (3) and (5) it can be observed that the (V_n) depends on the compressive strength of concrete ($fc`$), the effective depth of beam (d), width of beam (b_w), ratio of bending reinforcement (ρ_w) and the ratio of shear reinforcement (ρ_v).

7. Experimental program

Seven reinforced concrete beams were cast in this investigation, all beams have a rectangular cross section with length (1200) mm, width (100) mm and average height (150) mm as shown in the Figure (3-I). The beams are designed as a simply supported to fail in shear under two concentrated loads, the bending reinforcement of beams consisted of two bars (Ø16) mm at the tension region and two bars (Ø16) mm at the compression region. In the shear design, all beams were reinforced with conventional steel bar has diameter (Ø5) mm @ 60 mm as shown in the Figure (3-II). The steel stirrups of these seven beams were designed according to (ACI 318-14) [17] and the shear strength was calculated from the equations (3-4) and (3-5) that is mentioned in section six.

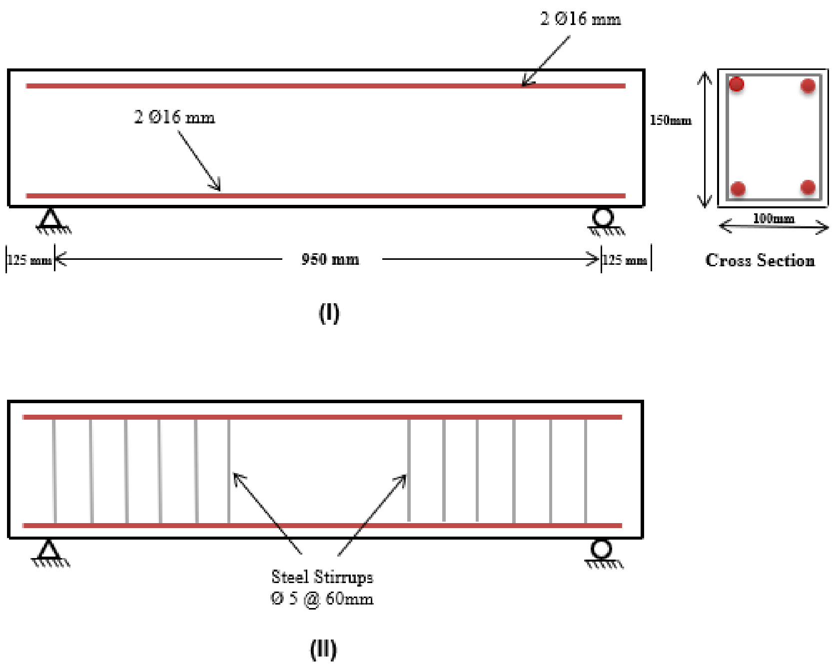

Figure 3. Beams reinforcement details

8. Results and Discussion

8.1. Effect of Waste Plastic (PET) Fibers on the Concrete Characteristics

8.1.1 Slump Test

The slump test was conducted to measure the workability of all fresh concrete mixtures according to ASTM C143 [18]. The slump test showed a large effect of the waste plastic (PET) fibers on the consistency and workability of concrete. The results indicated that, when increasing the (PET) fibers percentage and the value of (w/c) ratio remains constant, the workability of concrete decreased and became stiffer at the highest fibers content as shown in the Figure (4). The reason of reduction in the workability of concrete was attributed to the fibers shape which works to restrain the movement of materials within the mixture due to sharp edges and length of fibers compared with the aggregate.

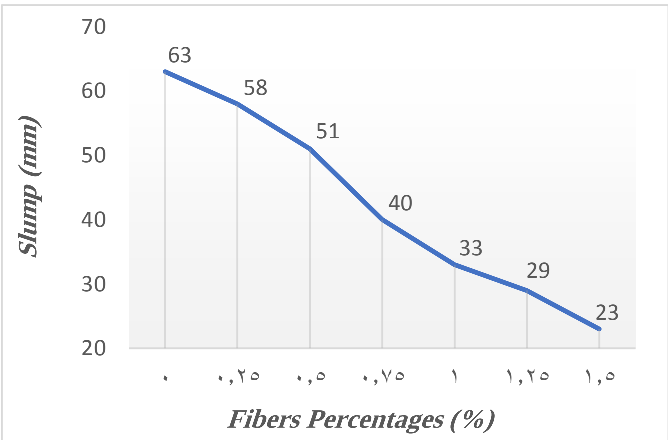

Figure 4. Effect of (PET) fibers on the workability

8.1.2. Compressive Strength Test

The compressive strength (***f'c***) for concrete cylinder was obtained by converting the test results of cubes (***fcu***) according to (BS EN 206-1) [19] as the following formula:

$$f'c = 0.8\,fcu \tag{6}$$

For each (PET) fibers percentage was tested, three cubes at (7) and (28) days were used to calculate the average of results as shown in the Table (7). The results showed that the compressive strength of concrete at (7) days in continuous increasing until the fibers percentage equal to (1%), but after that, the compressive strength was decreased with increasing the (PET) fibers percentage. As for the age of (28) days, a slight effect was recorded of fibers on the compressive strength of concrete and showed decreasing the strength with increase the fibers percentage (1.25% and 1.5%). The increasing in the compressive strength at (7) days can be interpreted by two means; the (PET) fibers worked as strengthening bridges which bind the parts of cement paste at early ages of the curing period when it was weak and fragile due to the hydration interactions were not complete. In addition, the presence of fibers within the mixture increases the amount of absorbed energy before the failure occurs and that led to increasing the loading capacity at the early ages. The reduction in the compressive strength at the age of (28) days with fibers percentages 1.25% and 1.5% lies in one interpretation, the (PET) fibers represented as weaknesses in the cement paste that became stronger by the end of the curing period.

Table 7. The density and compressive strength of concrete for all fibers percentages

Vf (%)	Density (KN/m3)	*f'c* (MPa)		Percentage Change (%)
		7 days	**28 days**	
0	2413.3	25.312	32.88	0
0.25	2412.94	26.672	33.016	+ 1.382
0.5	2409.6	27.184	33.326	+ 3.785
0.75	2408.8	27.368	34.632	+ 5.323
1	2401.9	27.904	35.264	+ 7.245
1.25	2397.07	24.608	32.392	- 1.489
1.5	2394.9	23.36	32.048	- 2.535

8.1.3. Splitting Tensile Strength Test

The splitting tensile strength of standard cylinder (150 x 300) mm was calculated at (7) and (28) days for all (PET) fibers percentages depending on the ASTM (C496-86) [20] as shown in the Figure (5) and Table (8).

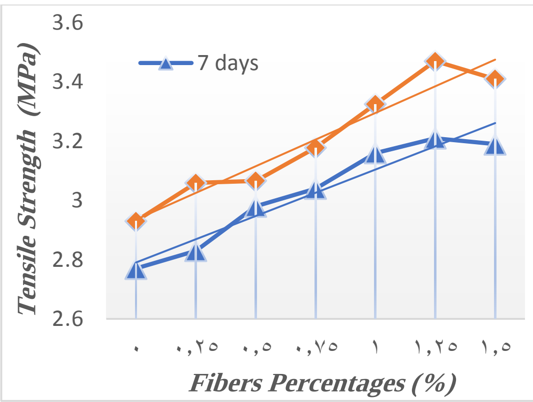

Figure 5. Relationship between the splitting tensile strength and fibers percentages

Table 8. Splitting tensile strength and width of max. axial crack of cylinders

Vf (%)	Stress (MPa)		Width of Max. Axial Crack (mm)
	7 days	**28 days**	
0	2.77	2.93	---
0.25	2.83	3.059	1.64
0.5	2.98	3.066	1.23
0.75	3.04	3.178	0.86
1	3.16	3.325	0.79
1.25	3.21	3.47	0.63
1.5	3.29	3.564	0.51

The results of stress refer that the splitting tensile strength was increased with the increase of (PET) fibers percentage until the percentage of (1.25%), also the width of the axial crack for cylinder became very small and the parts of the specimen have a good cohesion together after failure, contrary to the control specimen that split into two parts after the test directly as shown in the Figure (6). Also, it observed that the control specimen failed suddenly with a high sound of the broken, while the cylinders with fibers percentage (1%, 1.25% and 1.5%) there is no noticeable sound. In other words, the concrete will be more ductile when using the (PET) fibers. This behavior was already expected with the presence of fibers due to increasing the interdependence of cement paste that leads to reduce the internal stresses and increase the ultimate applied load.

a) Comparison between the specimen of the highest (PET) fibers percentage and the reference after the test directly.

b) After hitting the specimen by the hammer for more than (136) times, it was separated a small part from the cylinder that contains the fibers percentage (1.5%).

Figure 6. Some of cylinders after the splitting tensile test

8.1.4. Static Modulus of Elasticity Test

The chord modulus method was used to calculate the value of the static modulus of elasticity according to **ASTM C469-02** [21]. This method is represented by the slope of chord drawn on the relationship curve between stress and strain from the longitudinal strain point that equal (50) microstrains to the point correspond 40% of the ultimate load.

As it is well known, the modulus of elasticity has a direct relationship with the compressive strength of concrete, but with the presence of (PET) fibers this concept does not apply to all fibers percentages. From the results of testing the specimens at the age of (28) days that are illustrated in the Figure (7) and Table (9), it is observed that the modulus of elasticity was decreased with increasing the fibers content, in spite of the specimens with fibers percentages (0.25, 0.5, 0.75 and 1%) have a higher compressive strength of the reference.

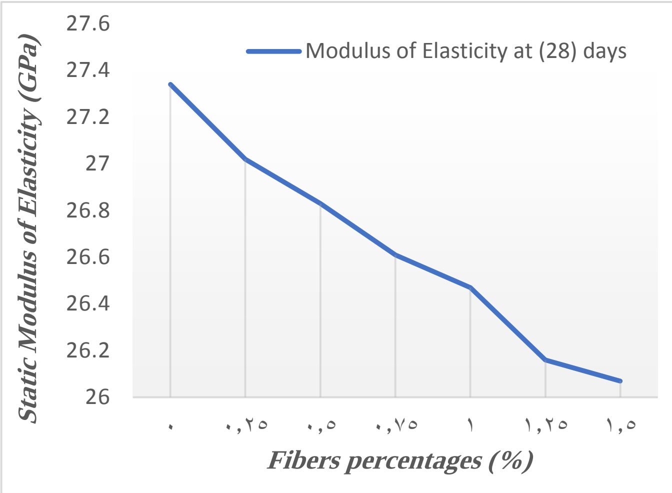

Figure (7) Relationship between the modulus of elasticity and fibers percentage

Table 9. Static modulus of elasticity and compressive strength for all fibers percentages at (28) days

Vf (%)	*f'c* (MPa)	*Ec* (GPa)	The reduction in *Ec* (%)
0	32.88	27.34	--------
0.25	33.016	27.02	1.17
0.50	33.326	26.83	1.865
0.75	34.632	26.61	2.67
1	35.264	26.47	3.178
1.25	32.392	26.16	4.316
1.5	32.048	26.07	4.645

This behavior can be explained by studying the relationship of the stress - strain curve which shows the increasing in the value of strain at fibers percentages (0.25, 0.5, 0.75 and 1%) was larger than the increasing in the stress due to developments of the forces of cohesion between the parts of cement paste with the presence of the fibers during the test, in addition, the modulus of elasticity of (PET) plastic is very low compared with the concrete. The Figure (8) shows some of specimens after the modulus of elasticity test.

Figure 8. Static modulus of elasticity test

8.1.5. Ultrasonic Pulse Velocity (UPV)

The test of ultrasonic pulse velocity was carried out depending on the requirements of **(ASTM C597 -09)** [22]. The values of ultrasonic pulse velocity are shown in Figure (9) for ages (7 and 28) days. From the results, a large effect of (PET) fibers on the pulse velocity can be noted, when increasing the fibers percentage will occur impedance for the wave and decreasing in the pulse velocity, because the waste plastic fibers make the structure of concrete more porous and lower density [2]. Also, it can be observed that the ultrasonic pulse velocity increased with the age progress of curing due to improving the chemical and physical properties of concrete as a result of continuing the hydration reactions.

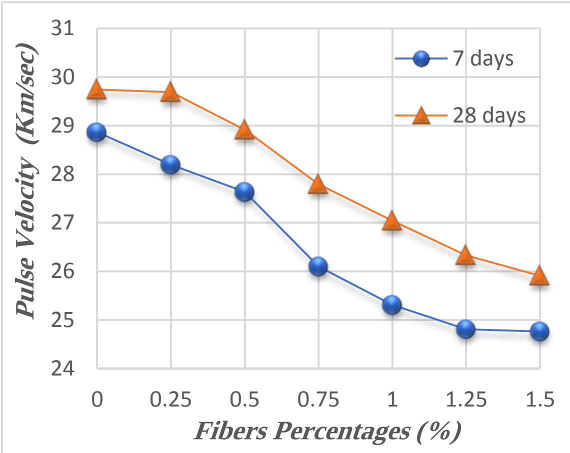

Figure 9. Relationship between the pulse velocity and fibers percentages

8.2. Effects of Waste Plastic Fibers on the Structure Behavior of Reinforced Concrete Beams

8.2.1. Shear strength

The main objective of this work is studying the effect of (PET) fibers on the shear strength of reinforced concrete beams. The results showed improvement in the shear strength of beams with the presence of waste plastic fibers in concrete and convert the mode of shear failure from sudden to ductile. The shear strength was recorded during the test at a moment of appearing the first crack, also, the value of deflection recorded for each (5kN) increasing in the applied load until the failure of the beam. Table (10) includes the details of the first crack and ultimate shear strength of all beams.

Table 10. The ultimate shear strength and first crack load of all beams

Vf (%)	Steel Stirrups	
	Pu **(kN)**	***Pcr*** **(kN)**
0	142.61	44.92
0.25	143.16	45.52
0.5	143.43	46.09
0.75	150.13	46.98
1	154.8	47.5
1.25	147.49	37.03
1.5	134.18	34.1

From the results, a relationship between the compressive and shear strength of concrete can be found, this confirms the (ACI 318-14) [17] equation (3) that was explained in section six. In spite of the increase of the first crack load for beams was slight with the increase of fibers percentages, but, this explains that the plastic fibers made the cement paste more interconnected and contributed by a little resistant to tensile stresses before occur the first crack. Likewise, the cracks are distributed on a larger area rather than one crack only, which can be noticed even in the bending region (between two concentrated loads). The optimum shear strength was recorded at fibers percentage (1%) and the highest increasing in shear strength was reached to (8.54%). The increasing of the ultimate load capacity of beams refers to the role of waste plastic fibers in improving the tensile properties of concrete and restrict the spread of cracks inside the concrete structure, but the reduction of ultimate load at fibers percentages (1.25% and 1.5%) possibly as a result of loss the workability of concrete and became more porous and lower density, in another word, due to the loss of the mixture homogeneity and balling the fibers.

8.2.2. Load – Deflection Curves

The relationships between the load and deflection of all beams are shown in Figures (10). The curves show that the value of deflection at the same load level was decreased with the presence of waste plastic fibers that worked to bridge the cracks. It is worth mentioning that the reduction in the beams deflection at first crack with the presence of the waste plastic fibers was slight, because of the resistance of plastic fibers to tensile stresses started at a moment of the growth in the crack, whereas in the case of using steel fibers, the resistance to tensile stresses start before the appearance of the first crack and that leads to increase the load of the first crack and significantly decreasing in the deflection of beams. Generally, all types of fibers are able to bridge the cracks and redistribute the stresses in the beam body to carry more load with a smaller deflection at the same load level.

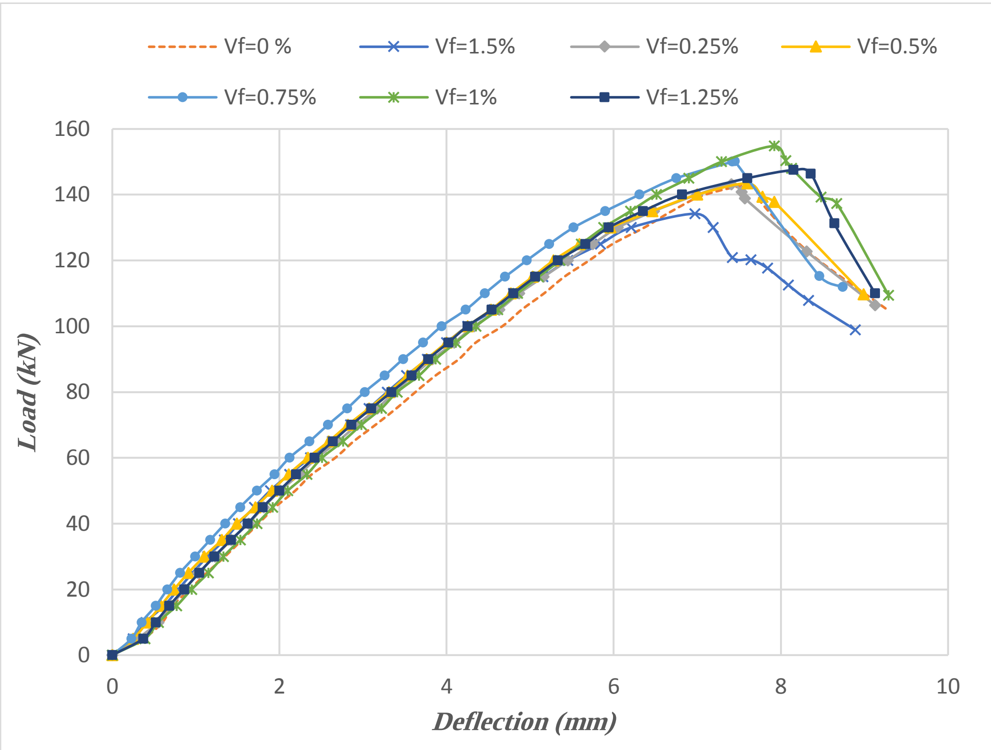

Figure 10. The relationship between load and deflection at mid span of all beams

Figure (11) shows the amount of absorbed energy (toughness) of all beams by calculating the area under the load-deflection curve.

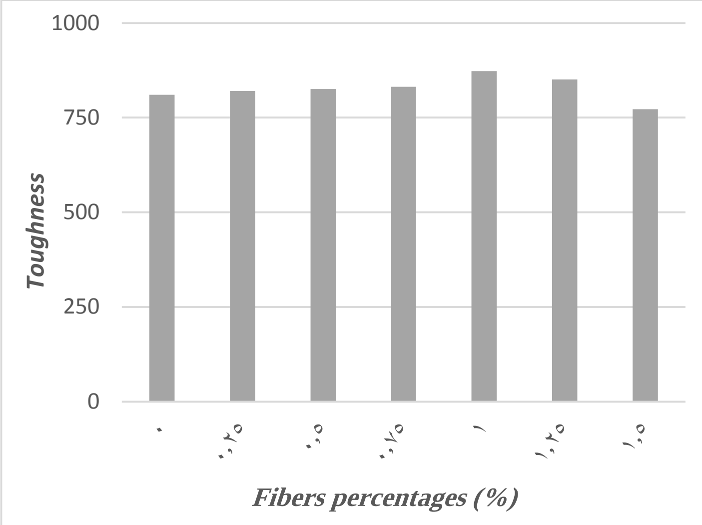

Figure 11. The area under load-deflection curve of all beams that were calculated by the AutoCAD and Excel software

9. Conclusions

Some conclusions can be drawn based on the experimental results that were described in previous sections as the following:

- The increasing of waste plastic fibers percentage led to decrease the workability of concrete mixes and the value of this decreasing was almost (63.49%) at fibers content (1.5%).
- The effect of waste plastic fibers on the compressive strength of concrete was slightly for all fibers percentages and the highest increasing percentage was recorded at fibers content (1%) that reached to (7.24 %).
- The splitting tensile strength was increased with increasing of fibers content until the percentage of (1.25%) that recorded a significant increase in tensile strength by (18.43%) at 28 days. In addition, the width of the axial crack for cylinders became very small after failure with incorporating the waste plastic fibers.
- Each of the ultrasonic pulse velocity and modulus of elasticity of concrete was decreased with increasing the fibers percentage that reached to (12.6%) and (4.64%) respectively at (28) days and fibers content (1.5%).
- The shear strength and absorbed energy of reinforced concrete beams were increased with incorporating the plastic fibers in concrete until the fibers percentage of (1%) that recorded increase in the applied load about (8.54%).
- A slightly increasing in the first crack load has been observed with increase (PET) fibers content until (1%) which recorded an increase of (5.74%).

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