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Effects of Waste Plastic PET Fibers on The Fresh and Hardened of Normal Concrete

***Ali H. Allawi*[1], , *Abdulkader I. AL-Hadithi*[1], *Akram S. Mohmoud*[1]**

[1]*Civil Engineering deperatment, College of Engineering, University Of Anbar, Ramadi Anbar, Iraq.*

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ABSTRACT

In this paper, the laboratory experiments works were conducted to study the effect of adding recycle waste plastic as polyethene terephthalate PET fibers on the fresh properties as the slump test and hardened properties as a compressive strength, splitting strength, elastic modulus, ultrasonic pulse velocity (UPV), density, absorption, voids, flexural toughness and flexural rupture for the normal concrete. The parameter of this paper included percentage of fibers content (0%, 0.5%, 1%, and 1.5%). The geometric design of the PET fibers was a strip with dimensions 4mm width, 70mm length, and 0.035mm thickness. The aspect ratio of the PET fibers in this work was about 50. The results showed that the PET fibers improving the most properties of the normal concrete and on the other hand there is negative effect on some properties of concrete. There is a significant increase in flexural toughness, about 21.2%, while the compressive strength and splitting were increased by 5% and 18.8%, respectively. Besides this improving, using PET fibers conform to the principle of sustainability, which is reducing the pollution and the cost of waste plastic disposal. It's observed that properties of concrete as a static modulus of Elasticity and density were decreased with the fiber percentage increased.

1. Introduction

In this world, the polyethylene terephthalate PET most extensively plastic used to produce the containers and other items. According to the worldwide production, the PET production in the Asian market increase by more than 6.7 million tons per (Kim et al., 2010). However, if PET is not properly disposed of, it may trigger environmental and economic problems. Since the cost of solid waste disposal is that while landfill space is shrinking, recycling is the best option for converting waste into usable items. The efficiency of concrete reinforced with short plastic fibers is significantly improved, including its tensile strength and ductility, according to the findings. Short plastic fibers act as a bridging force around the crack, preventing it from spreading further (Alhozaimy & Shannag, 2009; Auchey, 1998; de Oliveira, Castro-Gomes, & Materials, 2011; Naaman, Garcia, Korkmaz, & Li, 1996; Wang, Wu, & Li, 2000) . (Kim et al., 2010) studied the effect of the PET on the mechanical properties of concrete. The results showed that the compressive strength and elastic modulus decrease with the fiber content increase; furthermore, the cracks due to drying shrinkage were delayed in the presence of PET fibers in concrete. (Choi, Moon, Kim, Lachemi, & Materials, 2009) reported that the use of recycled PET fibers industrial gives the environmental, economic and technical advantage to the construction industry sector. (Najm & Balaguru, 2002) evaluated the effect of the PET fibers with different aspect ratio on the controlling cracking. The results showed that the higher aspect ratio more effective in controlling cracking.

* *Corresponding author.-.*
E-mail address: ali18e107@uoanbar.edu.iq

(Li, 2005) investigated the effect of PET fibers shape on the plastic shrinkage cracking. The results showed that the fibers with polygonal shapes have more effective than the circular shapes

1.1. Aim of the Study

The aim of this study includes improving the mechanical properties of the concrete.

2. Experimental Work

2.1. Material Properties

2.1.1. Cement

The locally available materials were used in this paper, the ordinary Portland cement conformable with the (Standardization & Control, 1984) such as shown in table1.

Table 1 – Chemical and physical properties of Ordinary Portland cement

compositions	Result	The limitations of specification according (I.Q.S.) No.5/ 1984
Chemical properties		
CaO	66.26	---
Fe2O3	3.73	---
SiO2	19.11	---
Al2O3	6.42	---
MgO	1.45	Not more than 5 %
SO3	2.31	Not more than 2.5 %
Insoluble residue	0.96	Not more than 1.5 %
Lime saturation factor	0.91	0.66 — 1.02
Loss on ignition	2.2	Not more than 4 %
Major compounds of cement		
C3A	2.9	Less or equal 3.5 %
C2S	8.52	---
C3S	61.8	---
C4AF	7.07	---
physical properties		
Initial settling time	194 min.	Not less than 45 min.
Final settling time	245 min.	Not more than 10 h. (600 min.)
Fineness (cm2/gm.) by Blaine method	2600	Not less than 2300
Compressive Strength at 3 days (MPa)	16	Not less than 15 (MPa)
Compressive Strength at 7 days (MPa)	28	Not less than 23 (MPa)

2.1.2. Fine Aggregate (Sand)

As a fine aggregate, red sand was used in this paper. Fine aggregate was tested according to the (Specification, 1984) such as shown in table2.

Table 2 – Grading Test and properties of fine aggregate.

Test Type	Result	The limitations of specification according (I.Q.S.) No.45/ 1984			
Grading Test					
Sieve size (mm)	Passing %	Zone1	Zone2	Zone3	Zone4
10	100	100	100	100	100
4.75	98.2	100 - 90	100 - 90	100 - 85	100 - 95
2.36	84.8	95 - 60	100 - 75	100 - 85	100 - 95

1.18	70.6	70 - 30	90 - 55	100 - 75	100 - 90
0.6	58.5	34 - 15	59 - 35	79 - 60	100 - 80
0.3	27.8	20 - 5	30 - 8	40 - 12	50 - 15
0.15	4.8	10 - 0	10 - 0	10 - 0	15 - 0
Chemical and Physical properties					
% of SO3	0.25%	Not more than 0.5%			
% Passing 0.075 mm sieve	1.51%	Not more than 5%			
Specific gravity	2.65	---			
Absorption	0.85%	---			

2.1.3. Coarse Aggregate Gravel

Coarse aggregate was used with max size 10mm, specific gravity 2.65% and absorption 0.68%. Coarse aggregate was tested according to the (Specification, 1984), the grading and physical properties of the coarse aggregate are shown in table 3.

Table 3 – Chemical and physical properties of coarse aggregate.

compositions	**Result**	**The limitations of specification according (I.Q.S.) No.5/ 1984**
Grading Test		
Sieve size mm	Passing %	The limits of cumulative passing (%)
20	100	100
14	100	90 -100
10	80.7	50 -85
5	9	0 -10
Chemical and Physical properties		
% of SO3	0.03%	Not more than 0.1 %
Clay	1%	Not more than 2 %
Specific gravity	2.65	---
Absorption	0.68%	---

2.2. Mix Design

The perfect mixture with a good workability and compressive strength was designed according to the (Committee, 2005) Figure 1 shows the effect of the PET fibers on the workability of concrete. Table 4 shows the details of the mix design as a mix proportion and compressive strength at 7-day and 28-day. The high performance Superplasticizer concrete mixture.

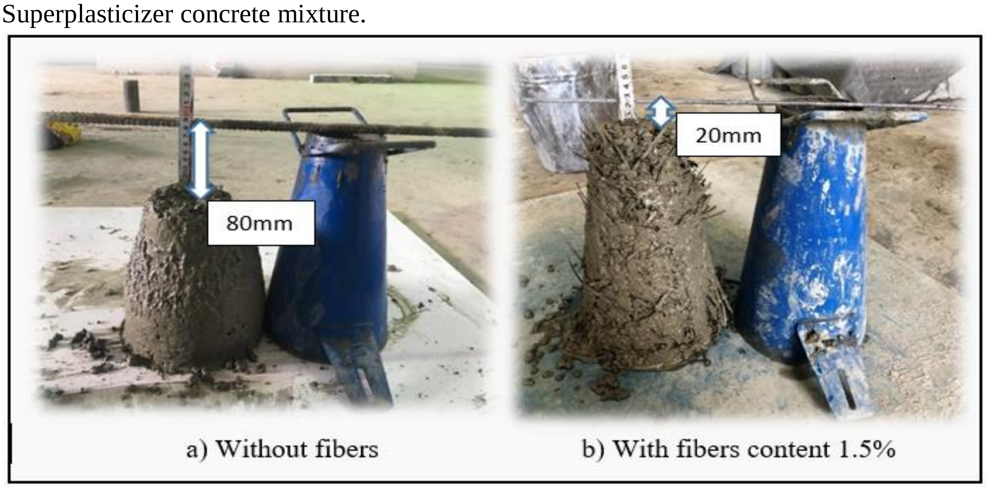


Fig. 1 Slump test.

Table 4 – Proportions and weights of mixture contents.

Mix	COMPONENTS kg/m3				W/C	Super % of Cement	Slump (mm)	Comp. strength MPa at 7 day	Comp. strength MPa at 28 day
	Cement	Sand	Gravel	Water					
A	430	900	1020	184	0.42	0.5%	110	31	37.5

2.3. Waste Plastic Polyethene Terephthalate (PET)

In this paper, the waste plastic PET were obtained by cutting the soft drink bottles to strips with the specified dimensions (70*4) mm as shown in figure 2. The waste plastic (PET) properties were illustrated in table 5.

a) Soft drink bottles bundles b) Cutting upper and lower part of bottle

c) Cutting the bottles to sheet d) Waste plastic PET

Fig. 2 Procedure of cutting the soft drink bottles.

Table 5 – Properties of waste plastic fiber (PET).

Dimensions (mm)	Aspect Ratio	Density (kg/m3)	Water Absorption	Color
70 * 4 * 0.35	50	1.38	0	Crystalline Colourless transparent

2.3.1. Tensile Strength of PET Fiber

According to the (standards, 1993), the test of PET fibers was carried out at the laboratory of the University of Technology as shown in figure 3. Table 6 was illustrated the results of the PET fiber test.

Table 6 – Results of the tensile strength of the (PET) fiber.

Type of plastic	Max Tensile stress MPa	Total percent elongation %	Elastic modulus (GPa)
polyethene terephthalate	110	28.57	0.59

Fig. 3 The tensile strength test of PET fiber.

3. RESULTS AND DISCASION

3.1. Workability

According to the specification (C. J. A. I. ASTM, 2003), the workability for fresh concrete was decreased with the fiber percentage increased and the maximum decreased was (75%) at the fiber percentage 1.5%. Figure 4 illustrated the effect of PET fibers on the workability. The decrease that happen in concrete workability when added the fiber attributed to the geometric design of the fiber (ribbon with sharp edges) and its role in mixture concrete, which is restrained the movement of the components of the mixture. (Bhogayata, Shah, Vyas, Arora, & technology, 2012) showed that the workability of normal concrete decreases as the addition of waste plastics fibers in concrete increases by up to 25%.

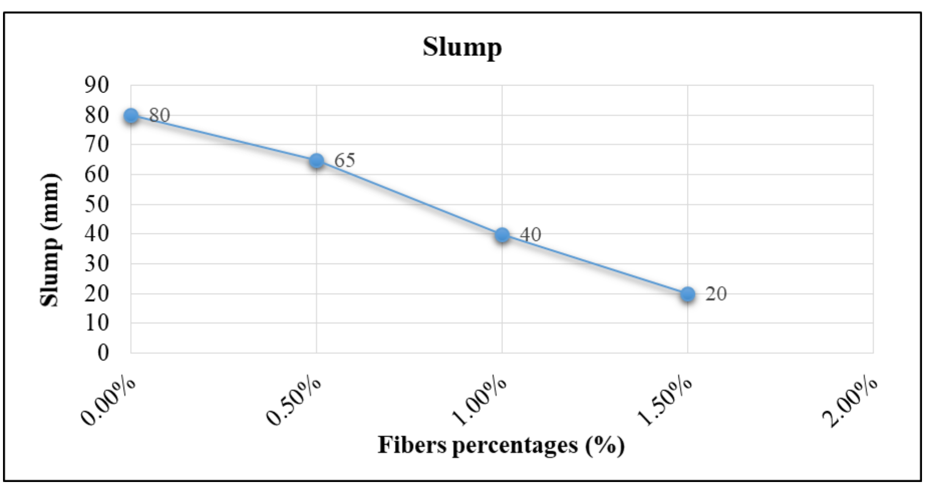


Fig. 4 Effect of PET fibers on the workability

3.2. Compressive Strength (f'_c)

In this research, the compressive strength has been calculated according to the (Standard, 2010). Three cylinder were tested for each fiber percentage and take the average. The compressive strength of normal concrete increased by 5% at the fiber percentage 0.5%, while decreased by 15.9% and 32.7% at the fiber percentages 1% and 1.5%, respectively as shown in figure 5 due to the role of fibers in connected the two opposite side of cracks (Al-Hadithi & Abbas, 2018a). Exegesis the increasing of the compressive strength is that the fiber work as a ribbon inside the mixture of concrete, which connected the composites of the concrete.

This lead to delay appearance the crack and increased the amount of the absorbed energy after the crack has happened because the fiber work as a bridge in this case between the two opposite sides of the crack, thus increasing the load capacity. But the decrease in the compressive strength at the fiber percentage 1% and 1.5% was due to increase of forming the gaps under the fibers inside the concrete as a result to increase the amount of fiber in concrete. Figure (4-3) illustrated the failure of the cylinders under the load that has been applied by the instrument and the cracks forms affected by the fiber percentage. (Malagavelli, Patura, & Engineering, 2011); (Pelisser, Montedo, Gleize, & Roman, 2012); (Ramadevi, Manju, & engineering, 2012); (Rahmani et al., 2013); (Prahallada, Parkash, & Technology, 2013) observed that the addition of PET and HDPE fibers in small amount results in an increase in compressive strength fc but the addition of large amount of PET particles reduce the strength.

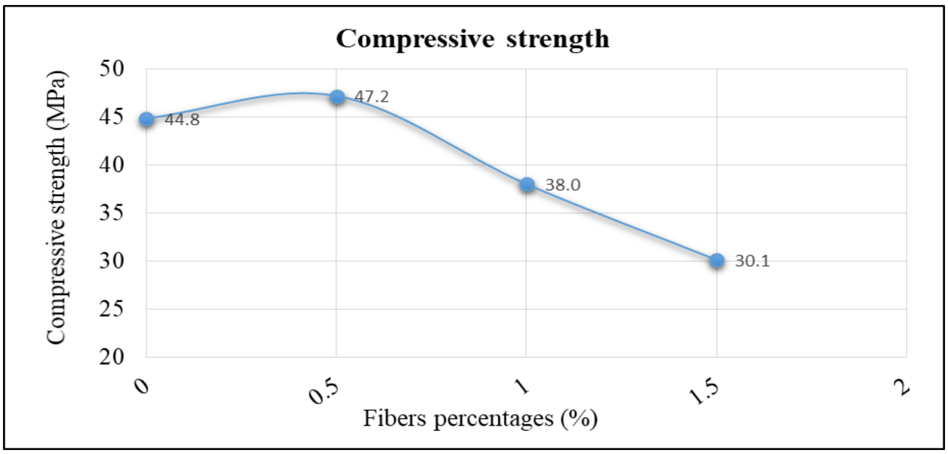


Fig. 5 Effect of PET fibers on the compressive strength.

3.3. Splitting Strength (f_t)

The splitting tensile strength has been tested according to the (C. J. U. S. A. I. ASTM, 2004) specification. The splitting strength of the normal concrete increased by 11% and 18.8% at the fiber percentages 0.5% and 1%, respectively, while decreased after these percentages by 13.5% as shown in figure 6. As a previous explanation in compressive strength (Al-Hadithi & Abbas, 2018b).

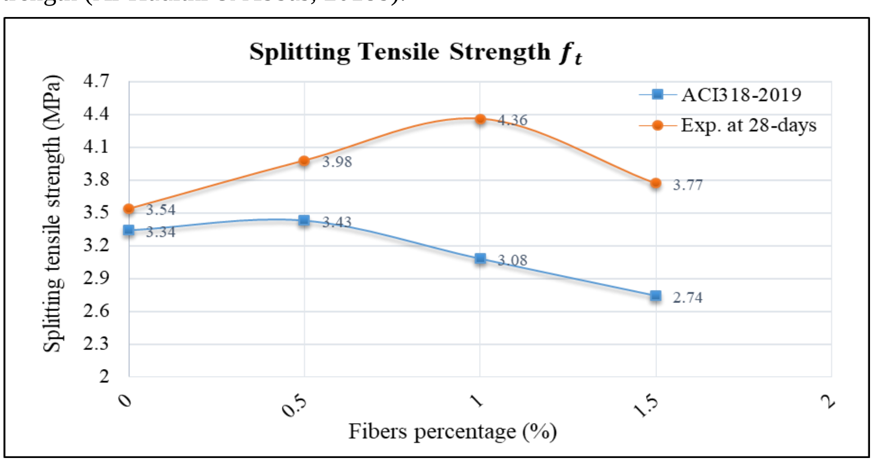


Fig. 6 Effect of PET fibers on the splitting strength.

3.4. Static Modulus of Elasticity (E_c)

Elastic modulus has been tested according to the (C. J. A. B. o. A. S. ASTM, 2002) specification which is defined the elastic modulus as being the slope of the stress-strain curve from the point strain 50 micro strains to the point 40% of the stress. The Elastic modulus of the normal concrete decreased with the fiber percentage increase and the maximum decreased value was by 17% at the fiber percentage 1.5% as shown in figure 7. The results above can be clarified based on the relationship between strain stress curve, which that there is a difference in the amount of increasing in the value of the strain when the concrete is contented the fiber. Existence the fiber was made the increasing value of the strain more than the increasing value of stress.

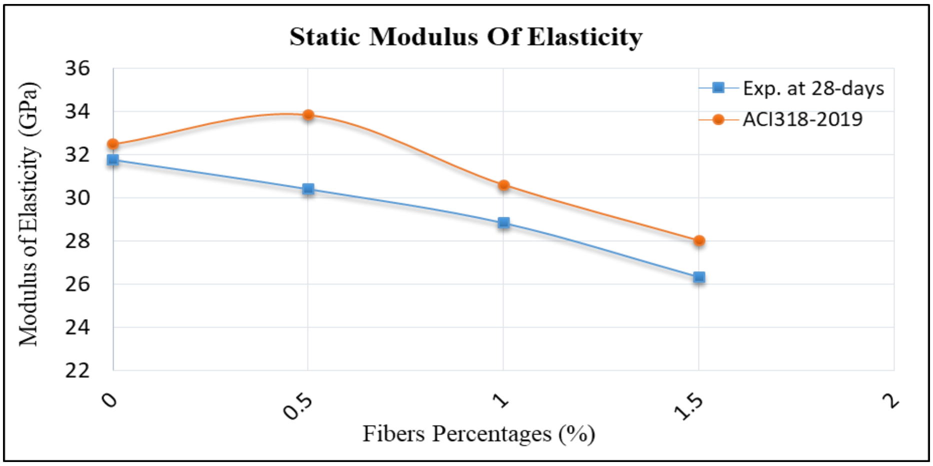


Fig. 7 Effect of PET fibers on the Static Modulus of Elasticity.

3.5. Ultrasonic Pulse Velocity (UPV)

According to the (C. J. A. I. Astm, West Conshohocken, PA, 2009), the Ultrasonic Pulse Velocity (UPV) of the normal concrete decreased with the fibers percentage increase and the maximum decreased value was by 9.1% at the fiber percentage 1.5%. Figure 8 was illustrated the effect of PET fiber.

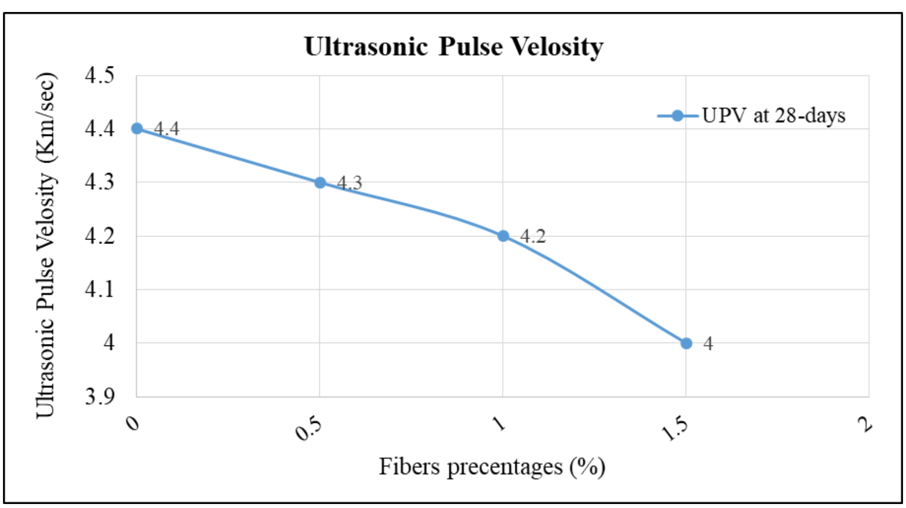


Fig. 8 Effect of PET fibers on the Ultrasonic Pulse Velocity.

The explanation of this decrease in the pulse velocity is the presence the porosity in concrete. The pulse is scattered as it travels through the porous concrete. As a result, the actual travel path of waves is longer than the distance between the transducers and the time pulse travel is longer because the pulse cannot travel through the porosity (Al-Hadithi & Abbas, 2018b).

3.6. Density, Absorption and voids in Hardened Concrete.

According to the ASTM C 642; Standard Test Method for absorption, density, and voids in hardened concrete (C. J. A. b. o. A. s. Astm, 2006), the Bulk density dry and after immersion in hardened concrete decreased by 2.5% at the fiber percentage 1.5% while the Volume of permeable pore space voids and absorption in hardened Concrete increased by 15% and 16.8% respectively, at the fiber percentage 1.5%. Table 7 showed the effect of the PET fiber on the absorption, density, and voids in hardened concrete. Increasing the PET fiber in concrete increases the porosity, thus lead to decrease the mass of specimen and increase the absorption during fill these porosities with water. The density equal mass/volume, therefore the density decreased with the mass decreased (Al-Hadithi & Abbas, 2018b; Albano, Camacho, Hernandez, Matheus, & Gutierrez, 2009; Araghi et al., 2015).

Table 7 – The results of density, absorption, and voids in hardened concrete.

Dimensions (mm)	0%	0.5%	1%	1.5%
Absorption of sample after inundation (%)	1.5615	1.8582	1.8608	1.8775
Difference %	----	+ 15.9	+16.08	+16.8
Absorption after immersion and boiling, (%)	1.5234	1.8198	1.8219	1.8386
Difference %	----	+16.2	+16.4	+17.1
Bulk density, dry (g1) (kN/m3)	23.47	23.01	22.99	22.88
Difference %	----	- 1.9	- 2	- 2.5
Bulk density after immersion (kN/m3)	23.84	23.43	23.42	23.31
Difference %	----	- 1.7	- 1.76	- 2.2
Bulk density after immersion and boiling (kN/m3)	23.83	23.42	23.41	23.30
Difference %	---	- 1.72	- 1.76	- 2.22
Apparent density (g2) (kN/m3)	24.34	24.02	24	23.88
Difference %	----	+ 1.3	+ 1.39	+ 1.88
Volume of permeable pore space (voids) %	3.5743	4.2048	4.2083	4.1876
Difference %	----	- 1.49	- 1.51	- 1.46

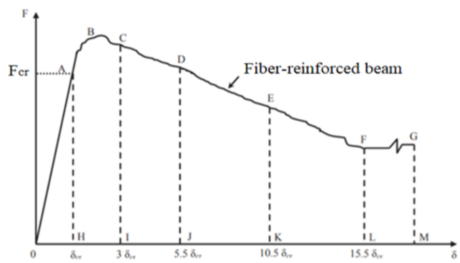
3.7. Flexural Toughness

Flexural toughness is an important characteristic to evaluate the effect of fiber on the post-peak behavior. This test was carried out to obtain the load-displacement curve, which is the area under this curve represented the energy absorption. All specimens were tested such as shown in figure 9 and the ASTM C 1018 (C. J. A. S. o. T. M. ASTM, USA, 1997) and JSCE Standard SF-4 (1995) (JSCE, 1984) methods are used to calculate the flexural toughness.

a) Fiber percentage 0% a) Fiber percentage 0.5%

Fig. 9 Failure of specimen under flexural loads (toughness).

The toughness index I5, I10, I20, and I30 are calculated according to the (C. J. A. S. o. T. M. ASTM, USA, 1997), which is represented the toughness at the deflection 3 δ, 5.5 δ, 10.5 δ, and 15.5 δ respectively, such as shown in figure 10. Table 8 explained the value of the toughness index for all fiber percentage.



$$I_5 = \frac{AREA_{OABCIO}}{AREA_{OAHO}}$$

$$I_{10} = \frac{AREA_{OABDJO}}{AREA_{OAHO}}$$

$$I_{20} = \frac{AREA_{OABEKO}}{AREA_{OAHO}}$$

$$I_{30} = \frac{AREA_{OABFLO}}{AREA_{OAHO}}$$

$$R_{5,10} = 20(I_{10} - I_5)$$

$$R_{10,20} = 20(I_{20} - I_{10})$$

$$R_{20,30} = 20(I_{30} - I_{20})$$

Fig. 10 Toughness indices according to (C. J. A. S. o. T. M. ASTM, USA, 1997).

Table 8 – Toughness results according to the (C. J. A. S. o. T. M. ASTM, USA, 1997).

Fiber percentages		0%	0.5%	1%	1.5%
(C. J. A. S. o. T. M. ASTM, USA, 1997).	**Area under the curve**				
	δ	14.9	19.683	20.443	16.94
	3δ	27.786	40.483	53.066	40.083
	5.5δ	--	66.856	74.083	62.466
	10.5δ	--	86.566	86.47	78.723
	15.5δ	--	105.243	103.866	95.86
	δ	14.9	19.683	20.443	16.94
	Toughness index				
	I_5	1.863	2.054	2.594	2.365
	I_{10}	0	3.398	3.627	3.687
	I_{20}	0	4.402	4.231	4.648
	I_{30}	0	5.350	5.084	5.659
	Residual strength factor				
	R5,10	---	26.885	20.656	26.445
	R10,20	---	10.036	6.044	9.606
	R20,30	---	9.480	8.525	10.110

According to (JSCE, 1984) method, the area (D_f) under the load-displacement curve up to the deflection (L/150) obtained, as figure 11. From this area, the flexural toughness factor (FT) is calculated, which its value indicates to the post-crack residual strength of the material when loaded to the deflection span/150. Table 9 explained the value of the (FT) for all fiber percentage.

Table 9 – Toughness results according to the (JSCE, 1984)

Fiber percentages		0%	0.5%	1%	1.5%
(JSCE, 1984).	**Area under the curve**				
	δ150	14.9	19.683	20.443	16.94
	D_f	27.786	40.483	53.066	40.083
	FT	--	66.856	74.083	62.466

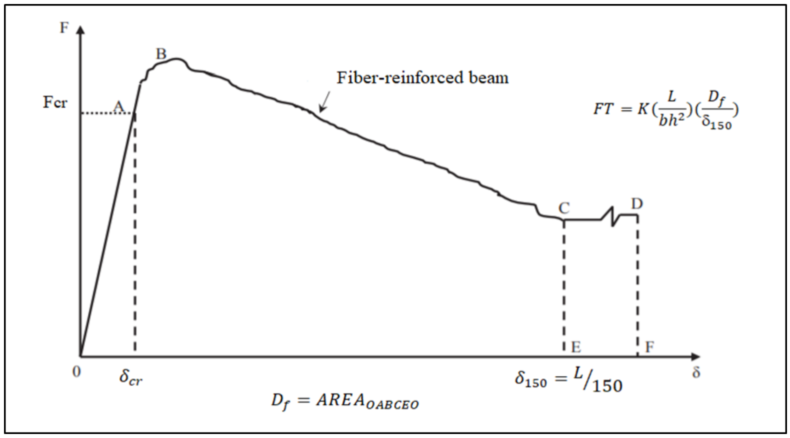


Fig. 11 Factor toughness strength according to (JSCE, 1984).

The maximum value of the modulus of rupture (f_r) was at the fiber percentage 0.5% compared with the control specimen without fiber, which is increased about 3.99%. While the failure mode of the specimen changes from the collapse to the failure with appeared the crack and the width of this crack decreased with the fiber percentage increased, such as shown in figure 12. The plastic in concrete works like a crack arrester during the propagation of the crack and bridging the concrete. All results of the modulus of rupture (f_r), cracks width, and ultimate load were shown in the table 10.

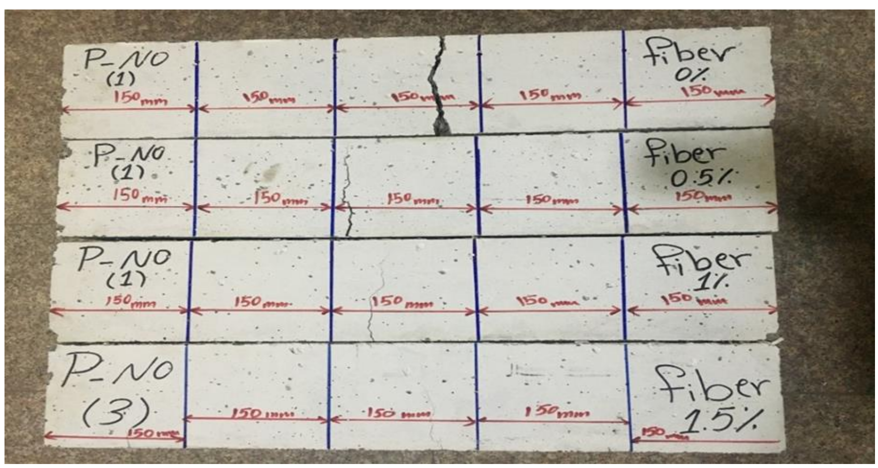


Fig. 12 Effect of the PET fibers on the cracks width of prisms.

Table 10– Results of the modulus of rupture, cracks width, and ultimate load.

Fiber percentage%	Crack width	Ultimate load	modulus of rupture f_rMPa	Change %
0	collapse	44.173	5.889	
0.5	3.5	46.013	6.135	3.99
1	1.109	40.493	5.339	-9.09
1.5	0.46	38.946	5.129	-13.43

As a result, the effect of the waste plastic on the toughness index and flexural toughness factor was very clear for the all specimens with the fiber content. The toughness index for the I5 was increased about the 28.18%, while the Flexural toughness index was increased about 59.57%. The explanation of the behavior is that the fiber carried the portion of the stress due to the distribution of stress after the cracks are happening.

4. Conclusions

1. The workability decreased by 75% at the fiber percentage of 1.5% due to the role of fibers in restrict and bridging the concrete.
2. The compressive strength and splitting strength were increased by 5% and 18.8% at the fiber percentage 0.5% and 1%, respectively. As the previous explanation in workability.
3. The Elastic modulus was decreased by 17% at the fiber percentage of 1.5% due to an increase in the strain of the concrete with the presence of PET fibers.
4. The Ultrasonic Pulse Velocity and the bulk density were decreased by 9.1% and 2.5% respectively due to the increase porous and this makes the path of wave longer than the path of the wave in concrete without fibers.
5. The flexural toughness and modulus of rupture of the normal concrete increased with the fiber percentage increase until to the 1% and then decreased with the fiber increased after this percentage, where the I5 increased by 21.2% for the flexural toughness and by 4% for the flexural rupture at the fiber percentage1%, compared with the reference specimen.

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