Journal of Engineering and Applied Sciences 13 (24): 10282-10290, 2018
ISSN: 1816-949X

The Effects of Adding Waste Plastic Fibers on the Flexural Toughness of Normal Concrete

Abdulkader Ismail Al-Hadithi and Mustafa Ahmed Abbas
Department of Dams and Water Resources Engineering, College of Engineering,
University of Anbar, Ramadi, Anbar, Iraq

Abstract: This study aims to apply the concept of sustainability to reduce the environmental pollution which is represented by the accumulation of waste plastic of soft drink bottles. The Polyethylene Terephthalate (PET) fibers that were obtained from cutting the plastic bottles were added to the ordinary concrete with volume fraction (0.25, 0.5, 0.75, 1, 1.25 and 1.5%) to study the effect of these fibers on the flexural toughness and performance of Fiber-Reinforced Concretes (FRC). The flexural toughness was calculated according to ASTM C1018 and ASTM C1609 in addition to ASTM C78 that was adopted to measure the modulus of rupture for all fibers percentage.The results indicate to enhance each of the modulus of rupture and toughness indices with the presence of the waste plastic fibers in concrete until fiberscontent 1.25% which has the highest percentage of increase in the modulus of rupture that reached to 8.88%) at 28 days.

Key words: Waste plastic fibers, toughness indices, flexural, rupture, sustainability, rupture

INTRODUCTION

Concrete is an extensively used material in the construction of buildings and bridges, it is characterized by a good resistance to the compressive stresses but weakly for the tensile forces. For this reason, many researchers studied the effect of various types of fibers on the properties of concrete to enhance the toughness and tensile strength. The use of (PET) fibers as secondary reinforcement in concrete had a wide interest by researchers in the recent years which is considered one of the feasible solutions to recycle the waste plastic accumulated.

The annual consumption of plastic drink bottles was estimated about 10 mln.ton, according to, statistics of 2007 that is equivalent to 250 billion bottles and grows about up to 15% every year (Afroz *et al*., 2013). The statistics indicate to generation about 3 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 mln.ton) (Gourmelon, 2015).

The statistics of US Environmental Protection Agency (EPA) (Anonymous, 2014) for 52 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 mln.ton in contrast, only 2.8 mln.ton were recovered which means 9.1% from the total production of plastic.

Despite the possibility of re-producing the plastic after several steps of treatment operations but it is not economical and the quality of product unacceptable (Saikia and de Brito, 2012). 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 (Ouda *et al*., 2017) or convert it to fuel by the methods of pyrolysis (Wong *et al*., 2015) but did not indicate to reduce the use of plastic and control on the quantities produced. The best solution to this problem is recycling the waste plastic by using it with other materials to produce materials have properties better than the original condition such as the concrete (Agamuthu and Faizura, 2005; Al-Manaseer and Dalal, 1997; Kim *et al*., 2010).

The low cost of recycled fibers is one of the most important causes that encourage the use of these fibers in the reinforced concrete structures and for getting rid of amounts of waste plastic that increase day by day in addition to solving the problem of corrosion of the steel fibers. Also, the common types of plastic characterized by the high chemical stability and non-biodegradable (Webb *et al*., 2012). The use of waste plastic fibers in the concrete construction reduces the total weight of the building comparatively and that lead to increase the resistance of construction to earthquake forces which depend on the mass of the structure (Kilic *et al*., 2003).

Corresponding Author: Abdulkader Ismail Al-Hadithi, Department of Dams and Water Resources Engineering, College of Engineering, University of Anbar, Ramadi, Anbar, Iraq

Table 1: The toughness indices of all fibers percentage (Faisal *et al*., 2016)

Fiber/ Fiber content (%)	Flexural toughness indices I_5	I_{10}	I_{20}	Difference percentage compared to normal (%) I_5	I_{10}	I_{20}
PRET-5						
0	4.96	09.94	12.87	0	0	0
0.25	5.29	10.81	13.96	6.7	8.8	8.5
0.50	5.26	10.95	15.12	6.0	10.2	17.5
0.75	5.09	11.21	15.70	2.6	12.8	22.0
1.00	5.13	11.23	15.84	3.4	13.0	23.1
1.25	5.07	11.04	15.76	2.2	11.1	22.5
1.50	5.02	10.96	15.12	1.2	10.3	17.5
PRET-10						
0	4.96	09.94	12.87	0	0	0
0.25	5.29	10.22	14.81	6.7	2.8	15.1
0.50	5.13	11.22	17.47	3.4	12.9	35.7
0.75	5.16	10.89	17.72	4.0	9.6	35.7
1.00	5.09	10.52	18.00	2.6	5.8	39.9
1.25	5.12	10.19	17.26	3.2	2.5	34.1
1.50	5.06	10.09	16.03	2.0	1.5	24.6

Many types of fibers are used in the reinforced concrete structures such as carbon, steel, glass and nylon. This indicates the benefit of using the fibers to increase the toughness and tensile strength of concrete. There are many scientific researches that clarify the effect of plastic fibers on the properties of concrete in process of fracture the concrete, fibers work to bridge the cracks in cement paste and increases the matrix resistance for propagating it before pull out or rupture the fibers (Daniel *et al*., 2002; Wang *et al*., 1987; Silva *et al*., 2005).

Faisal *et al*. (2016) studied the effect of Polyethylene Terephthalate (PET) bottles as a ring-shaped on the toughness strength of concrete. The purpose of cutting the bottles by this shape is to ensure failure in the yield rather than the pull out that occurs in the case of fibers. They cut soft drink bottles with diameter 60±5 mm to produce rings have a width 5 and 10 mm which added to the concrete by percentages (0.25, 0.5, 0.75, 1, 1.25 and 1.5%) for each width of fibers. Thus, the total number of specimens that were tested with the references was 14 that have dimensions 150 mm width, 150 mm depth and (500) mm length according to the ASTM (1997). They found a clear effect of ring-shaped (PET) fibers on the toughness indices as shown in the Table 1.

Pelisser *et al*. (2012) mentioned that the properties of concrete are enhanced when using the Polyethylene Terephthalate (PET) fibers with volume fractions 0.05, 0.18 and 0.30%. They found when the length of fibers equal to 20 mm, the flexural strength increases in the rate of 10.1% at 28 days and the addition of (PET) fibers with volumetric content 0.18 and 0.30% improved the impact resistance and absorption characteristic of concrete. They calculated the toughness indices at age 28 days for concrete with fibers length 10, 15 and 20 mm and volume fraction 0.30% according to (ASTM-C1018) (ASTM, 1997) and (ACI-544.2R) (Anonymous, 1999) as shown in the Fig. 1.

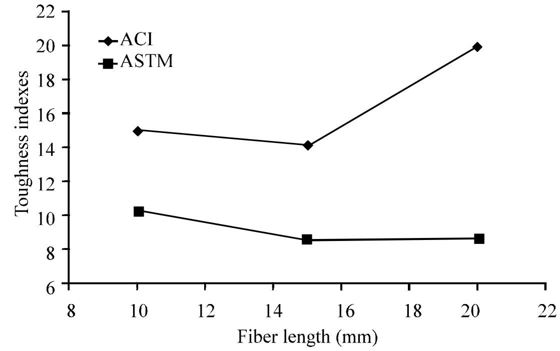

Fig. 1: Toughness indices of (FRC) with volume fraction 0.30% at 28 days (Pelisser *et al*., 2012)

Research significance: Recently, the use of sustainable materials has been observed in many fields due to the environmental and economic considerations. Therefore, the use of recycled plastic fibers certainly an important step towards sustainability. Also as is well known, many types of fibers are used to improve the structural performance and mechanical properties of the concrete member but little is known about the influence of recycled fibers on the toughness indices and post-crack strength of normal concrete. In addition, this research is an attempt to solve the problem of corrosion the conventional steel fibers by using recycled fibers that reducing the total weight of concrete.

MATERIALS AND METHODS

Coarse aggregate (gravel): The natural crushed gravel with the maximum size passing from the sieve of 14 mm was used in this investigation, the gravel cleaned and washed by municipal water several times and allowed to dry in the air. Table 2 show the physical properties and grading of the coarse aggregate according to the Iraqi Standard Specification (I.Q.S.) No.45/1984 (Anonymous, 1984a-c) and ASTM C33 specifications (2002) (Anonymous, 2002), the dry density of coarse aggregate that was used in the experiment is 1650 kg/m^3.

Fine aggregate (sand): The 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 (IQS) No. 45/ 1984 (Anonymous,

Table 2: Grading test and physical properties of coarse aggregate

Type of test Grading test	Results	The limit of specification according (I.Q.S.) No.45/1984 (Anonymous, 1984)
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		
SO_3 (%)	0.03 (%)	Not more than 0.1 (%)
Clay	1 (%)	Not more than 2 (%)
Specific gravity	2.67	-
Absorption	0.68%	-

Table 3: Grading test and physical properties of fine aggregate

Type of test Grading test	Results	The limit of specification (I.Q.S.) No.45/1984 (Anonymous, 1984)			
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					
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 (%)	-			

1984a-c) and ASTM C33 specifications (2002) (Anonymous, 2002) as shown in Table 3, the dry density of fine aggregate is (1750) kg/m^3.

Cement: The ordinary Portland cement (CEM I 42.5R) was used in this study, the chemical composition and physical properties conform to the Iraqi standard specification (I.Q.S.) (No. 5/1984) (Anonymous, 1984) for the ordinary Portland cement as shown in Tables 4 and 5 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.

Waste plastic 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 Fig. 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 plan of casting the specimens

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.

Table 4: The chemical properties of ordinary Portland cement

Items	Test results	Specification limit (Anonymous, 1984)
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 (%)

Table 5: The physical properties of ordinary Portland cement

Type of test	Test results	Specification limit (Anonymous, 1984)
Initial settling time (min)	194 min.	Not <45 min
Final settling time (min) (600 min.)	245 min.	Not >10 h
Fineness (cm^2/g) by Blaine method	2600	Not <2300 MPa
Compressive strength at 3 days (MPa)	16	Not <15 MPa
Compressive strength at 7 days (MPa)	28	Not <23 MPa

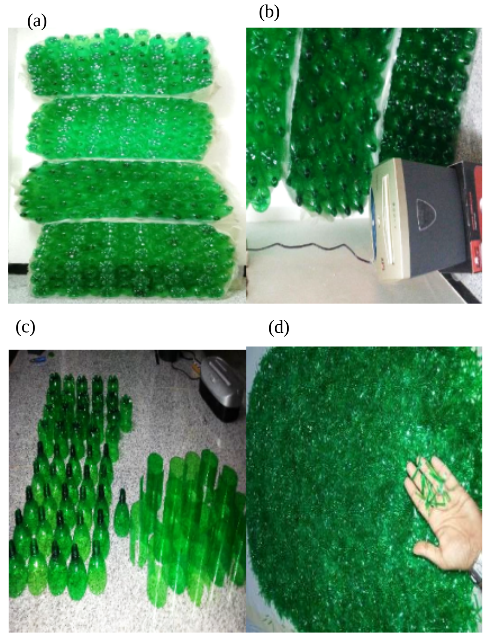

Fig. 2: Production of plastic fibers from the soft drink bottles: a) Large bundles of soft drink bottles; b) The paper shredder that was used for cutting the plastic bottles: c) Cutting the base and upper part of plastic bottles to use the remainingin the paper shredder and d) Waste plastic fibers

Fig. 3: The prisms of toughness test

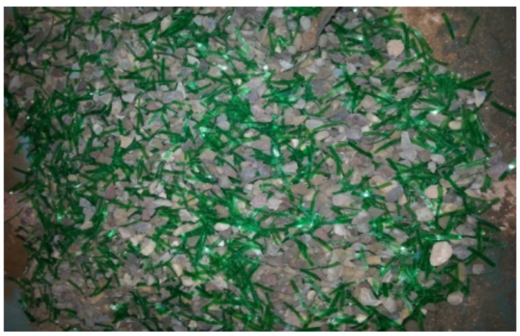

Fig. 4: The dry ingredients with waste plastic fibers

Procedure of casting: Fourteen concrete prisms were cast with dimensions 100×100×400 mm according to the ASTM C1018 (1997), ASTM C1609 (2005) and ASTM C78-02 (Anonymous, 2002a, b) to compute the flexural toughness and modulus of rupture for all fibers percentages as shown Fig. 3. The dry sand and saturated coarse aggregate with dry surface were mixed by the rotary mixer with speed 29.5 rpm during 3 min, after then the waste plastic fibers were added depending on the volume fraction and continued mixing the dry ingredients for 2 min only to distribute the fibers throughout the mixture and avoid forming fibers balls as shown in the Fig. 4. The water was added after mixing the cement with dry ingredients directly and the mixing continued for four minutes to achieve the best mix. After completing the process of concrete mix, it was poured into the moulds as three layers with vibrate each layer by a rod vibrator for 5 sec in order to get a full compaction. The top surface of moldswas smoothed by the hand trowel after 15 min from compaction the last layer. Then, all specimens were covered by the polyethylene sheets and left one day in the laboratory to be ready for curing stage.

Fig. 5: The machine of flexural test

Modulus of rupture test: The 7 specimens were tested under four-point load (with span length of 300 mm) according to ASTM C78-02 (Anonymous, 2002a, b) by the flexural machine type (WDW-200E) at age of 28 days in the laboratory of the Department of Production Engineering and Metallurgy in University of Technology as shown in the Fig. 5.

The modulus of rupture of all prisms was calculated depending on the location of the fracture as follows. When the fracture appears in the middle third of the span length then Eq. 1:

$$f_r = PL/bd^2 \quad (1)$$

Where:

f_r = Modulus of rupture (MPa)
P = Ultimate applied load (N)
d = Average depth of prism (mm)
b = Average width of prism (mm)
L = The span length between supports (mm)

When the fracture appears outside the middle third of the span length but no more than 5% of the span length, then Eq. 2:

$$f_r = 3Pa/bd^2 \quad (2)$$

where, a is the average distance measured on the surface tension of the prism between the line of fracture and the nearest support (mm).

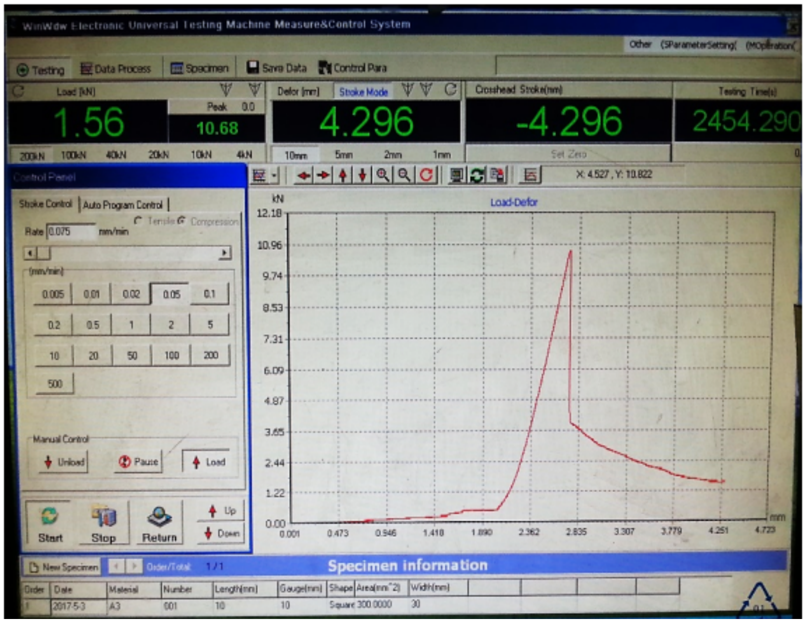

Fig. 6: The software of flexural toughness machine

Flexural toughness test: Toughness is a significant characteristic for Fibers Reinforced Concrete (FRC) that is calculated to determine the load carrying capacity of concrete before the cracking stage. The flexural toughness test was conducted as per ASTM (1997) and ASTM C1609/C1609M-05, (2005) under 3rd-point flexure. However, rather than the Linear Variable Displacement Transducers (LVDTs) that is fixed on the side of the prism to measure the deflections during applying the load, the software of testing machine computes the values of deflection with increasing the applied load from the readings of the load cell and draws the relationship between load and deflection as illustrated in the Fig. 6, depending on the ASTM C1609 (2005), the rate of increase in net deflection that was input in the software is 0.075 mm/min to get an accurate relationship between the load and deflection for calculating the amount of absorbed energy at certain deflection values (especially, the energy of post-cracking).

According to ASTM (1997) the toughness index defined as the ratio of the energy that is absorbed for a given d eflection to the energy that is absorbed at a deflection of the first crack where the absorbed energy is the value of the area under the load-deflection curve as shown in the Fig. 7.

The toughness indices are defined by I_5, I_{10} and I_{20} which represent the toughness at deflection corresponding to 3, 5.5 and 10.5δ, respectively where δ is the value of deflection at the first crack and the accuracy of calculating the toughness Indices (I) depends on the accuracy of measuring the value of this deflection (δ).

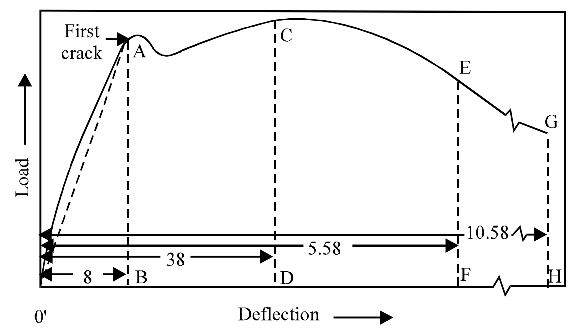

Fig. 7: The values of deflections that are used to calculate the toughness indices (ASTM, 1997)

The parameters used in evaluating the toughness indices according to the JSCE-SF4, (Anonymous, 1984) are similar to the parameters of ASTM C1018 (ASTM, 1997), except in JSCE-SF4 (Anonymous, 1984a-c), the curve of the load-deflection should be plotted until the deflection equal to L/150 where L is the net length of the prism. Also, this method calculates the toughness index I_{30} and Flexural Toughness factor (FT) that is dependent on the specimen geometry besides the test variables as described in Fig. 8 (Banthia and Trottier, 1995).

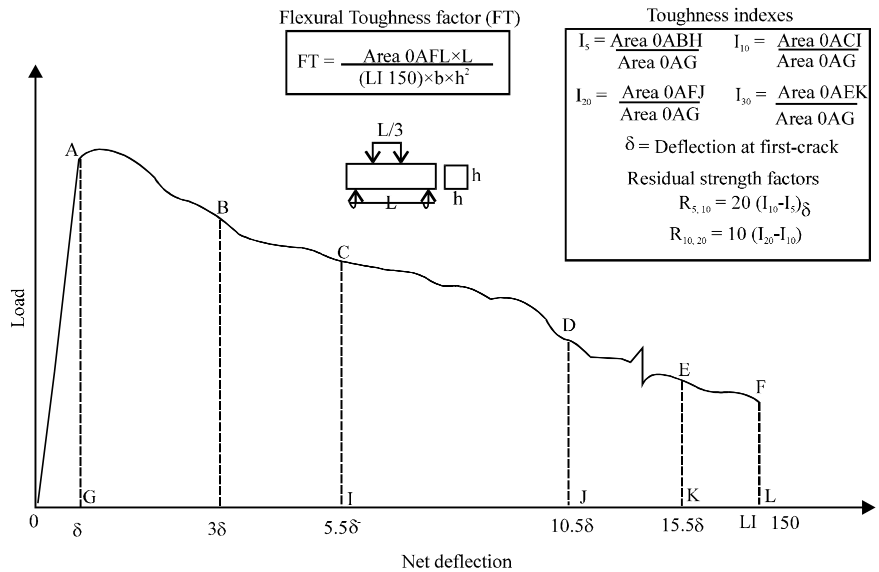

Fig. 8: Calculation of the toughness indices (Banthia and Trottier, 1995a, b)

RESULTS AND DISCUSSION

The modulus of rupture (f_r) of all prisms was calculated at age of 28 days as shown in the Fig. 9. Also, the failure modes of these prisms are displayed in the Fig. 10.

From the results, it can be observed a clear effect of waste plastic fibers on the flexural strength of specimens that increased with increasing the fibers percentages until the percentage of 1.25%. As well, the prisms after the test indicated the contribution of the fibers to increase the cohesion of concrete parts at the failure and arrest cracks progression as shown in the Fig. 11 while the prism without fibers separated into two parts after the failure directly.

The reasons of decline in the modulus of rupture at the highest fibers percentage are probablyas a result of balling the fibers into the concrete or decrease the workability of the mixture that leads to making the concrete more porous. Figure 12 and 13 displays the values of the toughness indices (I_5, I_{10}, I_{20} and I_{30}) for all fibers percentages and Flexural Toughness factor (FT), respectively.

But the procedure of test the flexural toughness indices according to ASTM C1018 (1997) may be suffering from a human judgment error, especially in determining the deflection of first crack (Banthia and Trottier, 1995a, b; Gopalaratnam *et al*., 1991). For this reason, the flexural toughness also was calculated according to the ASTM C1609 (2005) which is considered an improved version of the ASTM C1018 (ASTM, 1997). As well, two

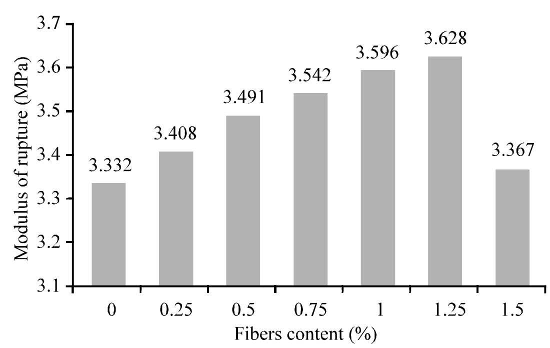

Fig. 9: Modulus of rupture for all concrete prisms

toughness parameters can be computed according to the ASTM C1609/C1609M-05 (2005) which are defined by (Fig. 10-13):

- $f_{100,\ 0.50}$: residual strength at a net deflection equal to 0.50 mm for span 300 mm or (1/600 of the span)
- $f_{100,\ 2.00}$: residual strength at a net deflection equal to 2.00 mm for span (300 mm) or (1/150 of the span)

The procedure of this specification is dependent on converting the load values to the stress in the cracked region rather than the values of energy and it is using a method to find the Post Crack Strength (PCSm) instead of the toughnes sindices as shown in the Fig. 14.

At a deflection of L/m, the value of the post-crack strength is given by the following relationship:

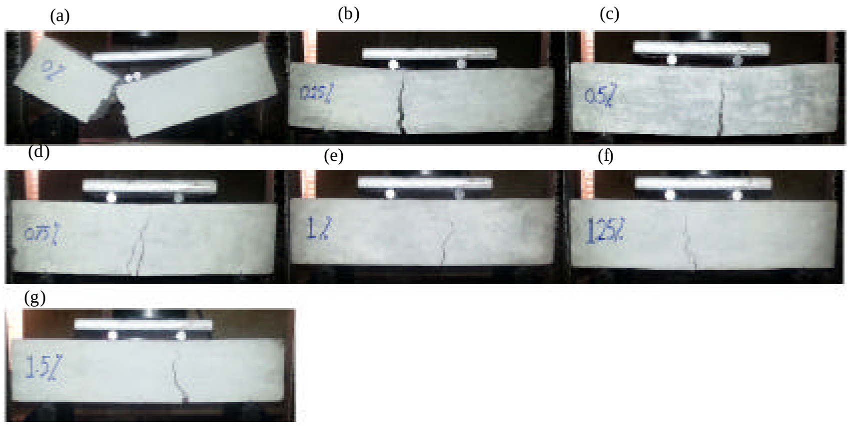

Fig. 10: All prisms after failure

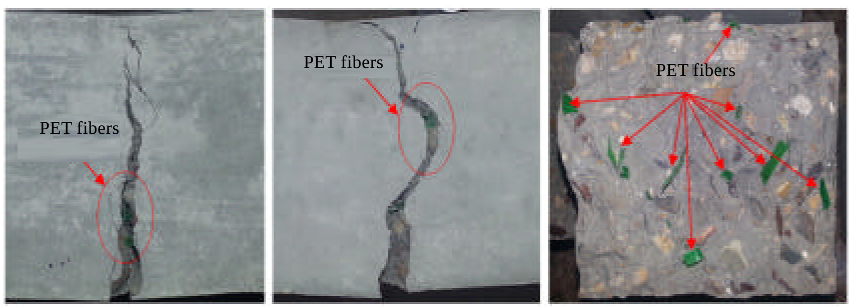

Fig. 11: Someprisms after failure and effect of PET fibers asstrengthening bridges

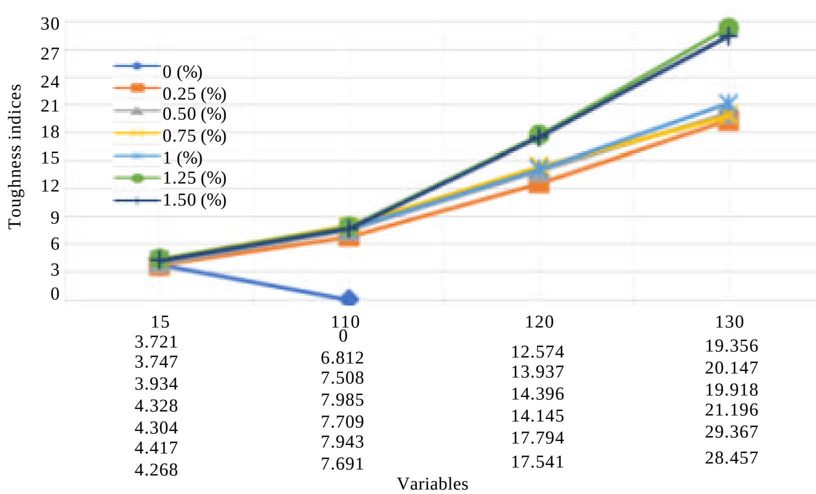

Fig. 12: Values of toughness indices for all prisms

$$PCS_m = \frac{\left(E_{post,m}\right)L}{\left(\frac{L}{m} - \delta_{peak}\right)bh^2}$$

Where:

$E_{post,m}$ = Post-peak energy value (up to a deflection of L/m)

L = Span length of the specimen (mm)

b = Width of the specimen (mm)

h = Height of the specimen (mm)

δ_{peak} = The deflection at the first peak load

m = Specified divisor of the span length that used to calculate a deflection value of interest

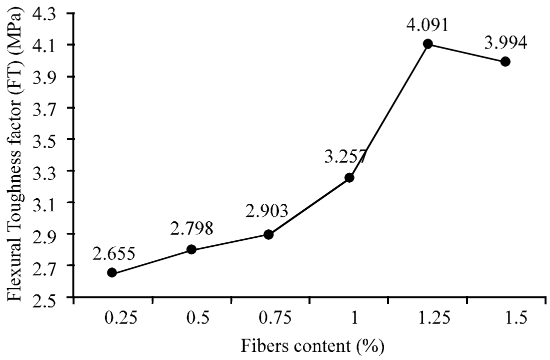

Fig. 13: Values of Flexural Toughness factor (FT) for all prisms

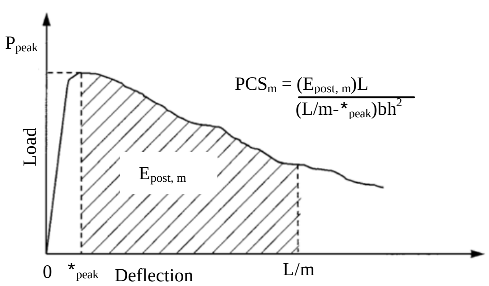

Fig. 14: Method of calculating the Post Crack Strength (PCSm) (ASTM, 2005)

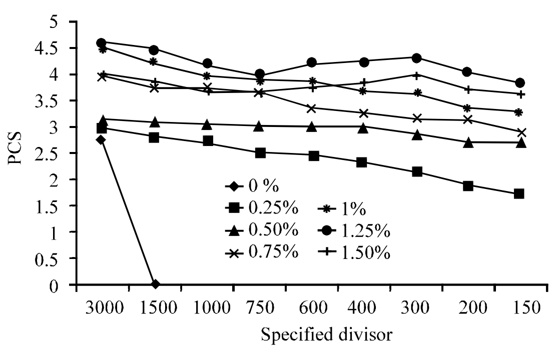

Fig. 15: The Post Crack Strength (PCSm) for all fibers percentages

The results of all prism according to the ASTM C1609/C1609M-05 (2005) are shown in the Fig. 15 from the results of flexural toughness, the effect of the waste plastic fibers on the absorbed energy of the post-crack was a clear for all prisms in contrast to the reference specimen that failed with a rapid softening after reaching to the peak load. The higher values of the Post Crack Strength (PCSm) were recorded at fibers percentage of 1.25% and it can be noted that this value returned to the increase with increasing the ratio of (L/m) for the specimens with fibers percentages 1.25 and 1.5%, this indicates the contribution of the waste plastic fibers in increasing the applied load after cracking. In other words, toughness characteristics and residual strength become better when using the plastic fibers and the extent of instability that can occur suddenly in the test will reduce depending on the volume fraction of fibers (Banthia and Trottier, 1995a, b).

CONCLUSION

Some conclusions can be drawn based on the experimental results that were described in previous studies as the following. With the presence of the waste plastic fibers in concrete, the modulus of rupture increased with the increase of fibers content until 1.25% and the highest percentage of increase was 8.88% at 28 days. The width of failure crack of prisms became very small with incorporating the waste plastic fibers and the parts of the specimen have a good cohesion together after the failure, contrary to the control specimen that split into two partswith a high sound of the broken after the test directly. The results of toughness indices (I_5, I_{10}, I_{20} and I_{30}) and Flexural Toughness factor (FT) refers to the role of waste plastic fibers in increase the amount of absorbed energy after the ultimate load and the highest values were at fibers content 1.25%. The values of Post Crack Strength (PCSm) of all fibers percentages are agreement with toughness indices calculations which indicates an increase in the strength after the ultimate load with the presence of waste plastic fibers where the highest value of the (PCSm) was at fiber content 1.25%.

REFERENCES

ASTM C1609/C1609M-05, 2005. Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading). ASTM International, West Conshohocken, Pennsylvania,.

ASTM, 1997. Standard Test Method for Flexural Strength of Steel Fiber Reinforced Concrete (Using Beam with Third-Point Loading). ASTM C1018-97, Philadelphia.

Afroz, M., M. Jobaer and M.M. Hasan, 2013. Performance of plain PET fibers to enhance the mechanical behavior of concrete under tension and shear. Intl. J. Sci. Eng. Technol. Res., 2: 1668-1672.

Agamuthu, P. and P.N. Faizura, 2005. Biodegradability of degradable plastic waste. Waste Manage. Res., 23: 95-100.

Al-Manaseer, A.A. and T.R. Dalal, 1997. Concrete containing plastic aggregates: Research on using post-consumer shredded plastic. Concrete Int., 19: 47-52.

Anonymous, 1984a. Iraqi standard specification for Portland cements. Iraqi Standards No.5, Iraqi Central Organization for Standardization and quality control (ICOSQC), Baghdad, Iraq.

Anonymous, 1984b. Iraqi standard specification for aggregate form natural sources for concrete and building construction. IQS/45-1984, IQS, Baghdad, Iraq.

Anonymous, 1984c. JSCE-SF4: Method of test for flexural strength and flexural toughness of fiber reinforced concrete. Japan Society of Civil Engineers (JSCE), Tokyo, Japan. https://www.elastoplastic.com/wp-content/uploads/2016/08/JSCE-SF4-Method-of-Test-For-Flexural-Strength-and-Flexural-Toughness.pdf

Anonymous, 1999. Measurement of properties of fiber reinforced concrete. ACI 544.2R-99, American Concrete Institute, Michigan, USA.

Anonymous, 2002a. ASTM C78-02 standard test method for flexural strength of concrete (using simple beam with third-point loading). ASTM International, Pennsylvania, USA. https://www.astm.org/DATABASE.CART/HISTORICAL/C78-02.htm.

Anonymous, 2002b. Standard specifications for concrete aggregates. ASTM C33-02, ASTM International, West Conshohocken, Pennsylvania. https://www.astm .org/DATABASE. CART/HISTORICAL/C33-02.htm

Anonymous, 2014. Municipal solid waste generation, recycling and disposal in the United States: facts and figures for 2012. United States Environmental Protection Agency, Washington, D.C., USA. https://www.epa.gov/sites/production/files/2015-09/documents/2012_msw_dat_tbls.pdf

Banthia, N. and J.F. Trottier, 1995b. Concrete reinforced with deformed steel fibers. Part II: Toughness characterization. ACI Mater. J., 92: 146-154.

Banthia, N. and J.F. Trottier, 1995a. Test methods for flexural toughness characterization of fiber reinforced concrete: Some concerns and a proposition. ACI. Mater. J., 92: 48-57.

Daniel, J.I., V.S. Gopalaratnam, M.A. Galinat, S.H. Ahmad and G.C. Hoff *et al*., 2002. Report on fiber reinforced concrete. ACI 544.1R-96, American Concrete Institute, Michigan, USA.

Faisal, S.K., J.M. Irwan, N. Othman and M.W. Ibrahim, 2016. Flexural toughness of ring-shaped waste bottle fiber concrete. MATEC Web Conf., 47: 01002-1-01002-6.

Gopalaratnam, V.S., S.P. Shah, G.B. Batson, M.E. Criswell and V. Ramakrishnan *et al*., 1991. Fracture toughness of fiber reinforced concrete. ACI. Mater. J., 88: 339-353.

Gourmelon, G., 2015. Global plastic production rises, recycling lags. Worldwatch Institute, Washington, D.C., USA. http://vitalsigns.worldwatch.org/sites/default/files/vital_signs_trend_plastic_full_pdf.pdf

Kilic, A., C.D. Atis, E. Yasar and F. Ozcan, 2003. High-strength lightweight concrete made with scoria aggregate containing mineral admixtures. Cem. Concr. Res., 33: 1595-1599.

Kim, S.B., N.H. Yi, H.Y. Kim, J.H.J. Kim and Y.C. Song, 2010. Material and structural performance evaluation of recycled PET fiber reinforced concrete. Cement Concrete Compos., 32: 232-240.

Ouda, O.K., S.A. Raza, R. Al-Waked, J.F. Al-Asad and A.S. Nizami, 2017. Waste-to-energy potential in the Western Province of Saudi Arabia. J. King Saud Univ. Eng. Sci., 29: 212-220.

Pelisser, F., O.R.K. Montedo, P.J.P. Gleize and H.R. Roman, 2012. Mechanical properties of recycled PET fibers in concrete. Mater. Res., 15: 679-686.

Saikia, N. and J. de Brito, 2012. Use of plastic waste as aggregate in cement mortar and concrete preparation: A review. Constr. Build. Mater., 34: 385-401.

Silva, D.A., A.M. Betioli, P.J.P. Gleize, H.R. Roman and L.A. Gomez *et al*., 2005. Degradation of recycled PET fibers in Portland cement-based materials. Cem. Concr. Res., 35: 1741-1746.

Wang, Y., S. Backer and V.C. Li, 1987. An experimental study of synthetic fibre reinforced cementitious composites. J. Mater. Sci., 22: 4281-4291.

Webb, H.K., J. Arnott, R.J. Crawford and E.P. Ivanova, 2012. Plastic degradation and its environmental implications with special reference to poly (ethylene terephthalate). Polym., 5: 1-18.

Wong, S.L., N. Ngadi, T.A.T. Abdullah and I.M. Inuwa, 2015. Current state and future prospects of plastic waste as source of fuel: A review. Renewable Sustainable Energy Rev., 50: 1167-1180.