Behaviour of Waste Plastic Fiber Concrete Slabs Under Low Velocity Impact

Abdulkader Ismail Al-Hadithi[1] **Ahmed Tareq Al – Ejbari**[2] **Ghassan S. Jameel**[3]

Received: 26/6/2012 **Accepted: 18/3/2013**

Abstract

This research investigates the impact resistance of concrete slabs with different volume perecentage replacement ratios of waste plastic fibers (originaly made from soft drink bottles) as follows : 0.5%, 1% and 1.5%. Reference mix produced in order to compare the result. For the selected mixes, cubes with (100×100×100mm) were made to test compressive strength at age of (90) days. Flexural strength (Modulus of Rupture) test was also conducted using prisms sample of (500*100*100 mm) dimensions.

The low-velocity impact test was conducted by the method of repeated falling mass where 1400gm steel ball was used. The ball falling freely from height of 2400mm on concrete panels of (500×500×50 mm) having a mesh of waste plastic fiber.The number of blows that caused first crack and final crack (failure) were determined, according to the former obtained results , the total energy was calculated.

Results showed an improvement in mechanical properties for mixes containing plastic fibers compared with reference mix. For compressive strength the maximum increase in compressive strength was equal to (3.2%) at age of (90) days. Flexural strengths for mixes containing plastic fiber at ages 28, and 90 days are higher than that of these of reference mix. The maximum value of increaseing was (18%) for 28 days age of test and it was equal to (26%) for 90 days age of test for the mixture with plastic fiber content by volume equal to (1%) .

Results showed a significant improvement in low-velocity impact resistance of all mixes contining waste plastic fibers when comparing with reference mix. Results illustrated that mix with (1.5%) waste plastic fibers by volume give the higher impact resistance at failure than the others. The magnitude of an increase over reference mix was equal to (340%).

Keywords: Waste plastic , PET, Compressive strength, Flexural strength, Impact Resistance, Low Velocity Impact.

سلوك البلاطات الحاوية على ألياف الفضلات البلاستيكية تحت أحمال الصدم

عبد القادر اسماعيل الحديثي **أحمد طارق نعمان** **غسان صبحي جميل**

الخلاصة

يتضمن هذا البحث دراسة مقاومة الحمل الصدمي واطئ السرعة للبلاطات الخرسانية المحتوية على الفضلات البلاستيكية على شكل ألياف وبنسب حجمية هي (٠.٥%،١%،١.٥%) ومقارنتها مع خلطات

[1] Assist. Prof , College of Eng. – Anbar Univ.
[2] Lecturer, College of Eng. – Anbar Univ.
[3] Assist. Lecturer , College of Eng. – Anbar Univ

مرجعية (لا تحتوي على ألياف البلاستك) استخدمت مكعبات بأبعاد (١٠٠*١٠٠*١٠٠)ملم لفحص مقاومة الانضغاط ومواشير بأبعاد (٥٠٠*١٠٠*١٠٠)ملم لفحص مقاومة الانثناء (معايير الكسر) وبلاطات بأبعاد (٥٠٠*٥٠٠*٥٠)ملم لفحص حمل الصدم واطئ السرعة.

إن فحص حمل الصدم واطئ السرعة تم بطريقة الإسقاط المتكرر لكتلة كروية بوزن (١٤٠٠)غم تسقط من بعد (٢٤٠٠)ملم سقوط حر وتحسب عدد الضربات التي تسبب التشقق الأولي والتشقق النهائي (الذي يسبب الفشل) ومن ثم تحسب الطاقة، حيث بينت النتائج تطور في الخواص الميكانيكية للخلطات المحتوية على ألياف البلاستك مقارنة مع الخلطة المرجعية حيث كانت الزيادة في مقاومة الانضغاط هي (٣.٢%)عند عمر ٩٠ يوم بنسبة ١% ألياف بلاستك بينما كانت الزيادة في مقاومة الانثناء هي (١٨%و٢٦%) بعمر (٢٨ و ٩٠)يوم على التوالي للخلطة الحاوية على ١% ألياف بلاستك،كما بينت النتائج تطور واضح في حمل الصدم واطئ السرعة لكل الخلطات الحاوية على ألياف البلاستك وكانت النسبة المثلى هي (١.٥%) حيث كانت الزيادة هي (٣٤٠%).

1- Introduction

The concept of using fibers in concrete as reinforcement is not new. Over the last three decades numerous studies were performed on Fiber Reinforced Concrete (FRC). In the early 1960's only straight steel fibers were used and the major improvement occurred in the areas of ductility and fracture toughness, even the flexural strength increases was also reported. fiber reinforced concrete was primarily used for pavements and industrial floors. Currently, the fiber reinforced cement composite is being used for wide variety of applications including bridges, tunnels, canal linings, hydraulic structures, pipes, explosion resistance structures, safety valves, cladding and rolled compacted concrete. [1]

Concrete is considered a brittle material as it has low tensile strength and failure strain. It is difficult to suppress the formation and growth of cracks developed therein and is apt to be fractured by tensile load or dynamic load. To resolve these drawbacks and to prolong the service duration of concrete, fiber-reinforced concrete has been developed in which fibers are incorporated to improve the mechanical properties.[2] Fiber-reinforced concrete, or fiber concrete, is a composite. It takes the advantages of the high compressive strength of concrete and the high tensile strength of fibers. Furthermore, it increases the energy absorption capacity of concrete through the adhesion peeling off, pulling out, bridging, and load transmitting of fibers in the concrete,and improves the ductility, toughness, and impact strength .[2]

Concrete Developed by Waste Fiber

Recycled fibres from various sources have been studied as reinforcement in concrete, including tire cords, carpet fibres, feather fibers, steel shavings, wood fibers from paper waste, and high density polyethylene [3].

On the other hand, Concrete is the most heavily used construction material in the world. Adding a small fraction (usually 0.5-2% by volume) of short fibers to the concrete mix can increase the toughness (energy absorption) of concrete by orders of magnitude. Reduced shrinkage cracking has been observed even with fiber volume fractions as low as 0.1% of polypropylene fibers. Besides reducing the need for landfilling, the use of waste fiber for concrete reinforcement could lead to improved infrastructure with better durability and reliability. Potential applications could include pavements, columns, bridge decks and barriers, and for airport construction as runways and taxiways.[4]

Al – Hadithi [5] studied the effect of adding very small percentage of waste plastic fiber (waste of plastic beverage bottles) on the some of the mechanical properties of concrete. These percentages (0.1%) and (0.2%) by volume. Results obtained proved that adding of plastic fibres with these percentages lead to improvements in compressive strength and flexural strength appeared more clearly. Results proved also an increasing in densities of fiber concrete samples according to these made of reference mix.

Malagavelli [1] attempted to investigate concrete slabs using two different fibers namely PolyEthylene Terephthalate (i.e. mineral water bottles) and High Density Poly Propylene (i.e. disposable glasses). He presented analysis consisted of nine samples of slabs were examined and results were presented. It has been observed that the ultimate load carrying capacity increased considerably by using these two fibers. In addition, it has been observed that the compressive strength of cubes by using both the fibers with different percentages of the fiber was gradually increasing up to 1% fiber and gradually decreasing. The maximum compressive strength of cubes by using HDPP and PET fibers are 35.95 and 36.445N/mm^2 respectively.

Kandasamy [6] Attempted to study the influence of addition of polythene fibers (domestic waste plastics) at a dosage of 0.5% by weight of cement. The properties studied include compressive strength and flexural strength. He concluded that addition of 0.5% of polythene (domestic waste polythene bags) fiber to concrete would increases the cube compressive strength of concrete in 28 day to 5.12%; also it increases the cylinder compressive strength of concrete in 28 days to an extent of 3.84%; and increase the split tensile strength to an extent of 1.63%.

2- Experimental Program:

2-1 Materials

The materials that used in the present work are:

2-1-1 Cement

Ordinary Portland Cement (OPC) manufactured in the (Al – Shimalya) KSA was used in this work. The adopted type of cement confirmed to ASTM C150-86 [7] and to Iraqi specifications No. 5 – 1984. [8]

2-1-2 Fine Aggregate

The fine aggregate used is natural sand adopted from Al – Ramadi region. The sieve analysis showed that the sand conform to the requirements of the Iraqi specification (IOS) No. 45-84[9], zone (2), as shown in Table (1) .

Table (1) Grading of Fine Aggregate

Sieve Size (mm)	*Percent Passing*	
	Fine aggregate	*Limits of Iraqi Specifications No. 45:1984 (6) Zone 2*
4.75	90	90-100
2.36	75	75-100
1.18	55	55-90
0.6	40	35-59
0.3	14	8-30
0.15	3	0-10

2-1-3 Coarse Aggregate

Crushed gravel was used in this work brought from Samaraa region with maximum size of 12 mm. The aggregate grading is shown in Table (2). the limits of Iraqi Standards (IOS) No. 45-84 [9]) are shown in the same Table.

Table (2) Grading of Coarse Aggregate

Sieve Size (mm)	*Percent Passing*	
	Coarse aggregate	*Limits of Iraqi Specifications No. 45:1984 (6)*
20	100	100
14	100	90 – 100
10	55	50 – 85
5	9.85	0 – 10
2.36	0	-

2-1-4 Water

Tap water was used in concrete mixing, and curing.

2-1-5 Waste Fiber

Because of the rapid growth of the population in the recent years, there is an increase the waste plastic products. The type of waste plastic considered in this study is the soft drink bottles waste plastics. The waste plastic bottle is sliced to a small uniformed pieces with an average length of (34 mm) and width equal to about (2.5 mm). Then, the aspect ratio was (13.6). The major composition of these waste plastic bottles are Poly(ethylene terephthalate) (PET). PET exists as an amorphous (transparent) and as a semi-crystalline (opaque and white) thermoplastic material. Generally, it has good resistance to mineral oils, solvents and acids but not to bases. The semi-crystalline PET has good strength, ductility, stiffness and hardness while the amorphous type has better ductility but less stiffness and hardness [10]. The Common examples of PET are Fibres, barrier films, soft drink bottles (amorphous PET) etc. [11]. Plates (1) and (2) show pictures for the sliced pieces of the waste plastic used in this study.

Table (3) Some of the Physical Properties of (PET) Plastics

Type	Poly(ethylene terephthalate) (PET)
Density (g/cm^3)	1.41
Tensile (Young's Modulus) MPa	1700
Water absorbtion %	0.5
Melting temperature T_m	538
Ultimate strain ε %	180
Flexural modulus (rigidity) E MPa (3-point Flexure)	2,000
Yield strain ε % (Tensile)	4
Breaking strength σ_B MPa (Tensile)	50

Plate (1)

Plate (2)

2-2 Mixes:

Three concrete mixes were used in this work in addition to the reference mix (i.e. waste fiber =0%). Table (4) shows that the proportion of the prepared concrete mixes with (1:1.5:2.3) (by weight) of ordinary Portland cement: fine aggregate : coarse aggregate and the water to cement ratio of 0.4. Waste fiber is used as a ratio by volume of the mix as 0.5,1, and 1.5 percent .

Table (4) Mix Proportion used in this Study

Symbol	*Mix*	*Cement kg/m³*	*Sand kg/m³*	*Gravel kg/m³*	*Water kg/m³*	*Waste Fiber % (by Volume)*	*Waste Fiber kg/m³*
R	1:1.5:2.3	470	705	1081	188	-	-
F1	1:1.5:2.3	469.4	704	1079.5	187.7	0.5	5.5
F2	1:1.5:2.3	467	700.5	1074.1	186.8	1	11
F3	1:1.5:2.3	464.6	697	1068.7	185.8	1.5	16.5

Where:
R = Reference mix
F_1 = Mix containing (0.5)% waste fiber by volume.
F_2 = Mix containing (1)% waste fiber by volume.
F_3 = Mix containing (1.5)% waste fiber by volume.

Plate (3)

2 – 3 Molds, Mixing and Casting

Composite molds made of movable steel sides angels fixed with square wooden bed were used for casting the slab specimens. For each mix, three slabs of (50*50*5 cm) dimensions were used for casting concrete sample. In addition, two (50*10*10 cm) prisms also considered to determine the flexural strength. Three cube molds with (10*10*10 cm) were prepared for the test of the compressive strength. A (0.1) m^3 pan mixer was used to mix all the compositions of the mixes. The interior surface of the mixer was cleaned and moistened before placing the materials. Raw materials were first mixed dry for about one minute, after that water was added to the mix. The mixing process continued for about three minutes to get homogenous and consistence concrete. The plates below represent the process of mixing in the lab. Plates (4) and (5) for the concrete specimens casted in the lab.

Plate (4)

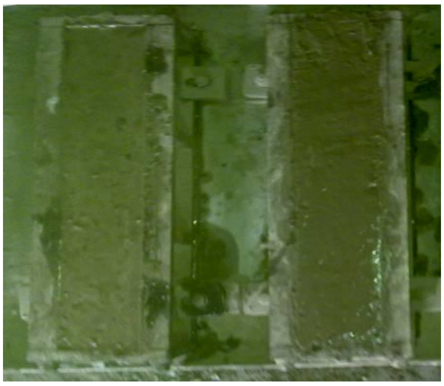

Plate (5)

2 – 4 Curing

The specimens were demolded after 24 hours in the laboratory. All specimens were kept under nylon sheets inside the laboratory for another (24) hours. They were demolded and submerged later in water basin to remain up to the time of tests.

3 - Tests:

3 -1 Compressive Strength Test:

Compressive strength tests were determined using (100*100*100) mm concrete cubes according to the B.S. 1881 Part116: 1983 [12] by using (2000 kN) capacity, ELE Digital Electric testing machine. The average compressive strength of three cubes were recorded at ages of (28 and 90) days.

3 -2 Flexural Strength Test:

Concrete prisms of (500×100×100) mm were prepared according to ASTMC192-02 [13]. Flexural test was carried out using three points loading according to ASTM C78-02 [14]. Modulus of rupture of two prisms was obtained for each testing age (28 and 90 days) for each mix .The maximum tensile strength in flexural (modulus of rupture) was calculated by using the following formula:

$fr = PL/ bd$

Where:

fr = modulus of rupture (flexural strength) , (MPa) .

P = Maximum load indicated by the testing machine, (kN).

b = width of specimen, (mm). , d = depth of specimen, (mm).

3-3 Low Velocity Impact Test:

Twelve slabs at age of 90-days with dimensions of (50 × 50 × 5) cm were tested under low velocity impact load (see Plate (10)). A steel ball of (1.4) kg and 55 mm diameter, was used for this test. The ball freely drop from 2400 mm height (see Fig. (1)). The test rig used for this test consists of three main components:

-A steel frame: holding the concrete slab rigidly during impact loading. The dimensions of this frame were designed to allow observing the specimens (square slab) from the bottom surface to show the failure developed during testing.

- A tube of a round section: represents the vertical guide for the falling mass to ensure mid-span impact.

The above variables are illustrated in Fig. (1) below.

Plate (6) Low Velocity Impact Test Setup

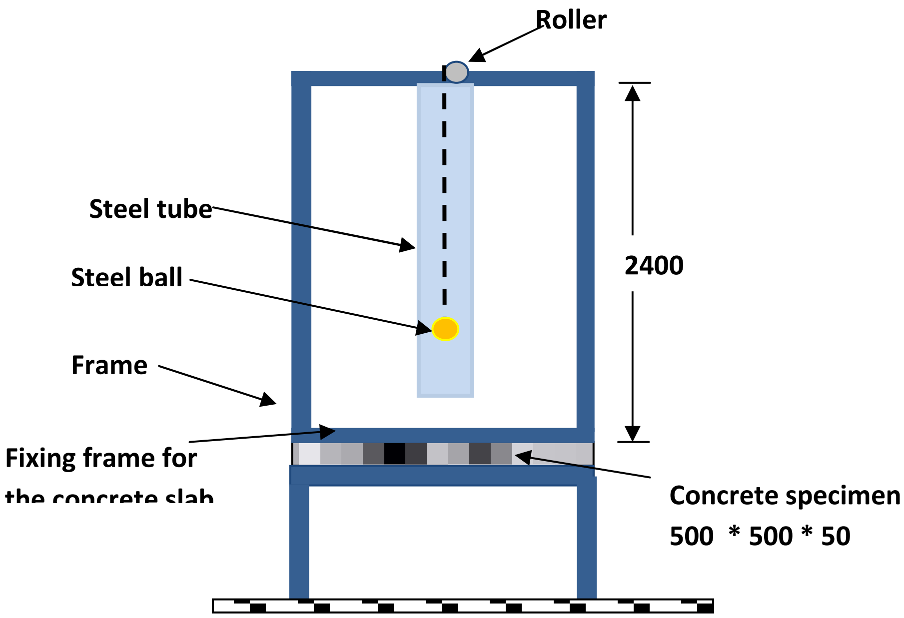

Fig. (1) A simplified sketch for the low velocity impact test setup

4- Results and Discussion:

4-1- Compressive Strength

Results of compressive strength test of all selected mixes at ages of (28 and 90) days are obtained from the average of three cubes, which tabulated in Tables (5) and (6). These results showed an increase in the compressive strength of concrete containing waste fiber over reference mix. The maximum increases of the compressive strength results were (4.4%) for (1.5%) waste fiber ratio at age 28 days. For (90) days results obtained the increase were (3.2%). The improvement of the compressive strength results is due to the ability of the fibers to elongate the crack path.

The relationship between compressive strength and (Waste: Concrete) ratio for all mixes are shown in Fig. (2), this figure shows that with an increasing in (Waste Fiber: Concrete) % by volume the compressive strength results are increased.

Table (5) Results of Compressive Strength for 28 days

No. of Mix	$V_{f\%}$ *(Waste Fiber: Concrete)% by Volume*	$f_{cu\ (28\ day)}$ *(Average) MPa*
1	0	50.2
2	0.5	50.3
3	1	50.7
4	1.5	52.4

Table (6) Results of Compressive Strength for 90 days

No. of Mix	*Vf% (Waste Fiber: Concrete)% by Volume*	*fcu (90 day) (Average) MPa*
1	0	52.2
2	0.5	53.0
3	1	53.5
4	1.5	53.9

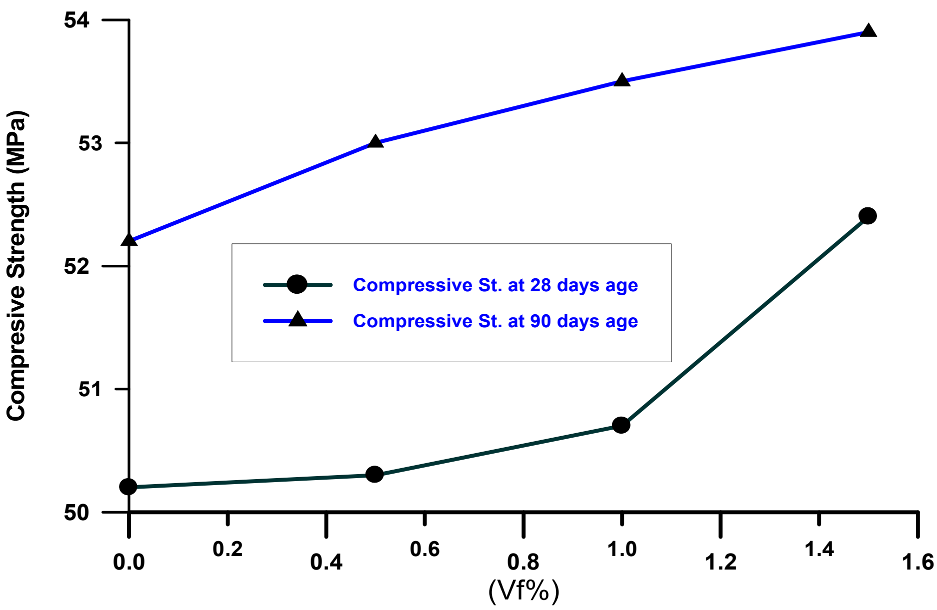

Fig. (2) The relationship between compressive strength at 28 and 90 days age and (waste plastic fiber: concrete (by volume)) %

4 – 2 Flexural Strength:

The results of flexural strength are tabulated in Table (7) and Table (8). These results were obtained for samples aged (28 and 90) days. Fig.(3) shows that the flexural strength for concrete increases with addition of waste plastic fiber. The percentage of increase varied from (10.5 to 18.4%). The maximum flexural strength result was for 1% (Waste: Concrete) percentage mix. The same thing is for the 90 days samples. It is increased by about (26%) from that of the reference mix. The cause of that increasing may be due to the influence of mixing action, the fibers are uniformly distributed throughout the concrete in all directions. In the fresh concrete, the uniformly distributed fibers reinforce against the formation of plastic shrinkage cracks. In the hardened concrete, the uniformly distributed fibers disallow the microcrack from developing into macrocracks and potential troubles. In addition, these fibers bridge and therefore hold together the existing macrocracks, thus reinforcing the concrete against disintegration (15).

Table (7) Results of Flexural Strength (Modulus of Repture) for 28 days

No. of Mix	*Vf% (Waste Fiber: Concrete)% by Volume*	*Modulus of Repture kPa*
1	0	8.55
2	0.5	9.45
3	1	10.12
4	1.5	9.67

Table (8) Results of Flexural Strength (Modulus of Repture) for 90 days

No. of Mix	*Vf% (Waste Fiber: Concrete)% by Volume*	*Modulus of Repture MPa*
1	0	9.05
2	0.5	10.28
3	1	11.4
4	1.5	10.53

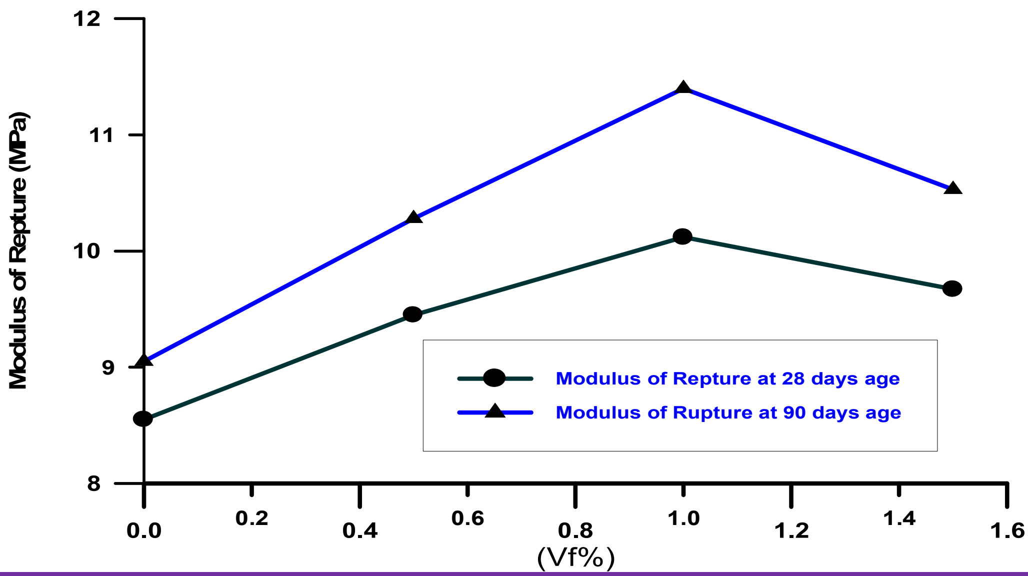

Fig. (3): The relationship between modulus of repture at 28 and 90 days age and (waste plastic fiber: concrete (by volume))%

4-3- Impact Resistance and Mode of Failure:

The impact resistance of concrete slabs was determined in terms of the number of blows required to cause complete failure of the slabs. The mass of (1400 gm) was repeatedly dropped for a (2400 mm) height up to the failure of slabs. Two sets of number of blows were recorded depending on the mode of failure: at first crack and at failure. Total fracture energy here is the product of the height of the drop (2.4 m) and weight of the dropped mass (1.4 kg) by the number of blows to failure. The results of low velocity impact tests of all mixes at age of (90) days are presented in Table (9) below, it can be seen that there is a significant improvement in the low-velocity impact resistance for the all mixes containing waste plastic over reference mix. Fig.(4) shows the effect of adding waste plastic add as a percentage by volume of the concrete at first crack and failure. It can be seen that, when the ratio of waste plastic: concrete percentage increased the impact resistance also increased. For a (1.5%) ratio the number of blows reached to (66) blows at failure while they recorded as (36) at first crack (each result average for three specimens). The increase of its impact resistance at failure over reference mix was (340%). Fig.(5) showed the relationship between impact resistance and waste plastic to concrete percentage ratios at first crack and failure.

The mode of failure under low velocity impact for all specimens for all mixes is shown in Plate (7) , the cracks starts from centre point (mean the centre of slab where mass is falling) then extend in all direction in lines perpendicular to its edges, It can be noticed that, at percentage of (1.5%) of waste fiber added to concrete, the specimen shows a good resistance to fracture due to the distribution of fiber across the concrete. That means the increase in tension stress, ductility, more energy absorption and bond strength.

Table (9) Results of impact test at 90 days age

Panels	Waste: Concrete %	No. of blows to first visual crack		No. of blows to failure	
		Results	Mean	Results	Mean
1	0	5	4	12	15
		5		18	
		3		15	
2	0.5	6	8	32	34
		8		33	
		10		37	
3	1	14	15	62	55
		15		71	
		16			
4	1.5	36	36	68	66
		37		65	
		35		66	

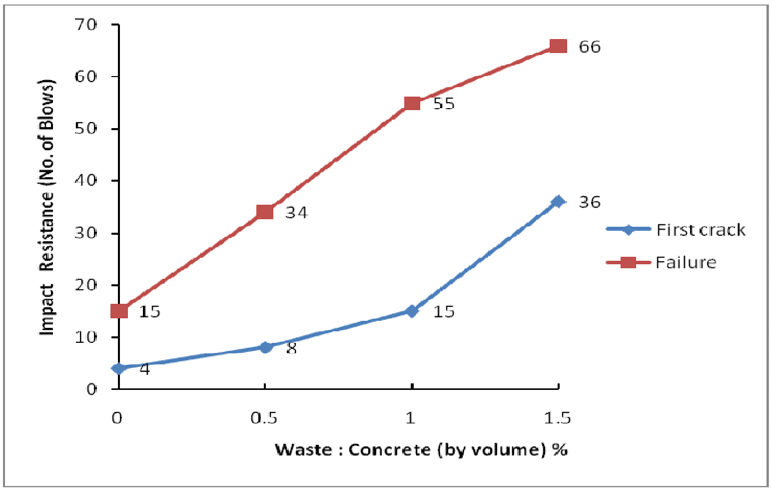

Fig. (4) The relationship between impact strength at 90 days age and waste: concrete (by volume) %

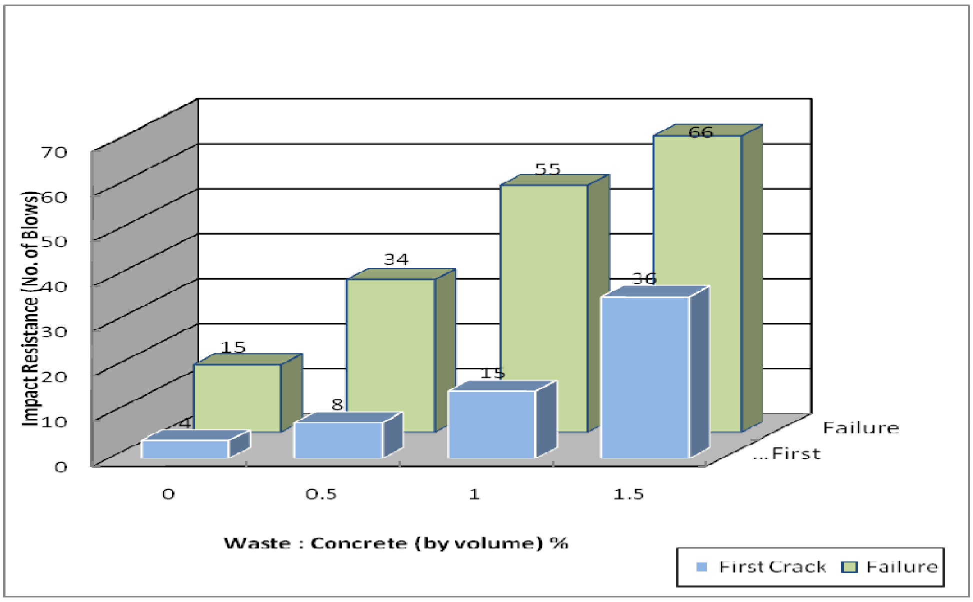

Fig. (5) Effect of waste fiber: concrete (by volume) percentage on the impact strength of concrete at 90 days age.

Table (11) Results of total energy for impact test at 90 days age

(Waste Fiber : Concrete by Volume)%	Total energy (N.m)	
	First visual crack	Failure
0	131.84	494.42
0.5	263.69	1120.69
1	494.42	1812.88
1.5	1186.56	2175.36

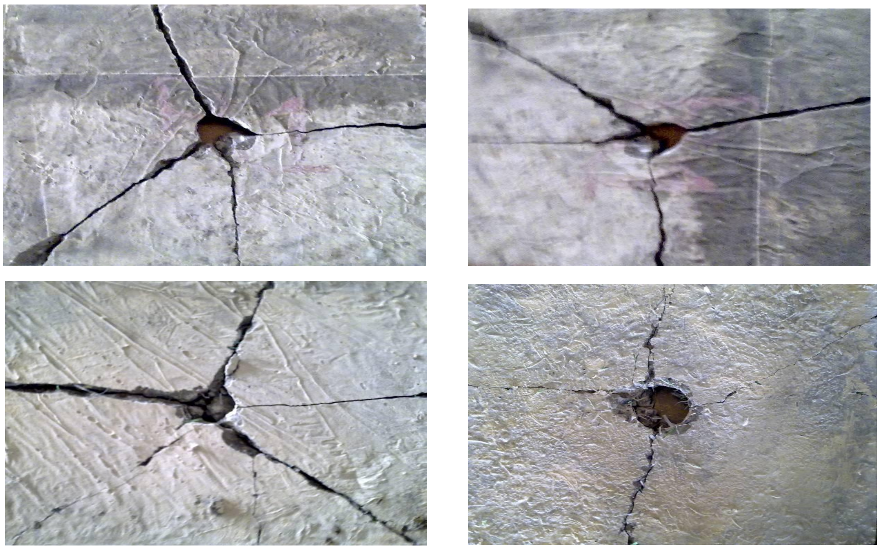

Plate (7): The mode of failure under low velocity impact for for all mixes

5 - Conclusions

Based on the expiremental work and results obtained in this study, the following conclusions can be presented:

1 - Addition of waste fiber with different ratios increses the compressive strength at ages 28, and 90 days relating to the original mix. The value of increaseing is about (4%) for 28 days and (3.2%) for 90 days age.

2 - Addition of waste fiber with different ratios increses the flexural strength at ages 28, and 90 days compared with the original mix. The max. value of increaseing is (18%) for 28 days while (26%) for 90 days of age for the mix with (1%) (waste fiber to concrete) percentages.

3 – A significent improvement in the low velocity impact resistance of all mixes modified with waste plastics over reference mix is realized. The increase in the waste fiber percentage gives higher number of blows at both first crack and failure compared with reference mix. The amount of increase varied between (126%) at (0.5%) percentage to (340%) for (1.5%) ratio at the failure.

References

[1] Malagavelli , Venu , and Rao., P.N. , “Effect of Non Bio Degradable Waste in Concrete Slabs” , International Journal of Civil and Structural Engineering, Volume 1, No 3, 2010. pp. 449 – 457.

[2] Kaiping, Liu ; Hewei, Cheng and Jing’en, Zhou “Investigation of brucite-fiber-reinforced concrete”, Cement and Concrete Research Journal, Volume 34, 2004, pp. 1981-1986.

[3] Wang, Youjiang, Wu , H.C. and Li, Victor C. "Concrete Reinforcement with Recycled Fibers ", Journal of Materials in Civil Engineering, Vol. 12, No. 4, 2000, 314-319.

[4]. Andrady, A. L. “Plastics and the Environment : Recycling of Carpet and Textile Fibers”, John Wiley & Sons, New York, 2003, Ch. 16, pp. 697-725.

[5] Al – Hadithi , Abdulkader Ismail, “Some Properties of Concrete Using Waste Plastic Fiber with a Very Small Percentages”. The First International Engineering Sciences Conference of Aleppo University (IESC 2008). 2-4/11/2008,Aleppo,Syria.

[6] Kandasamy, R., and Murugesan , R. , " Fibre Reinforced Concrete Using Domestic Waste Plastics as Fibres "Asian Research Publishing Network ARPN - Journal of Engineering and Applied Sciences, Vol. 6, NO. 3, March 2011, pp. 75 – 82.

[7] ASTM C150-89, "Standard Specification for Portland Cement" Annual Book of ASTM Standards, American Society for Testing and Materials, Section 4, Vol.04-02 1989,pp.89-92.

[8] Iraqi Standard Specification No.5, 1984, "Portland Cement"; (4pages).

[9] Iraqi Standard Specification No.45, 1984, "Aggregate From Natural Sources For Concrete" ,.

[10] United Nations Environmental Program UNEP , Division of Technology, Industry and Economics ,International Environmental Technology Centre "Converting Waste Plastics Into a Resource",(Assessment Guidelines), Osaka. 2009, pp. 63.

[11] Mark , J.E. , " Polymer Data Handbook ", Oxford University Press, Inc., 1999, pp. 558 – 560.

[12] B.S.:1881, Part 116, 1989,"Method for Determination of Compressive Strength of Concrete Cubes", British Standard Institution, pp.3.

[13] ASTM C192-02, "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory", Annual Book of ASTM Standard.

[14] ASTM C78-02, "Standard Test Method For Flexural Strength of Concrete {Using Simple Beam with Third-Point Loading ", Annual Book of ASTM Standard, Annual Book of ASTM Standards.

[15] Song,P.S. , Hwang,S. and Sheu,B.C. "Strength properties of nylon- and polypropylene-fiber-reinforced concretes", Cement and Concrete Research Journal, Volume 35 ,2005,pp. 1546– 1550.