Iraqi journal of civil engineering (IJCE)
P-ISSN: 1992-7428 ; E-ISSN: 2706-686X

Vol. 17 , No. 1 (2023) , pp. 42 ~ 51
DOI: 10.37650/ijce.2023.170105

Iraqi Journal of Civil Engineering

Journal homepage: https://ijce.uoanbar.edu.iq/

Flexural Behavior of Slurry Infiltrated Waste Plastic Fiber Concrete

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PAPER INFO

Paper history
Received: 09 /03 /2023
Revised: 10/06/2023
Accepted: 14/06/2023

Keywords:
SIFCON
Waste Plastic
Toughness
Flexural

ABSTRACT

Fiber Reinforced Concrete (SIFCON) is a new material with high performance and is a special type of Fiber Reinforced Concrete (FRC). The matrix of this type of concrete consists of a mortar that has the ability to penetrate a network of fibers. It is composed of mortar, water, a plasticizer (water reducer), and fibers. Previous studies have mostly used steel fibers, but in this research, waste plastic fibers were made from waste polyethylene terephthalate (WPET) by cutting soft drink bottles. Main objectives of this study are: Determination the influence of waste plastic fiber content on strength and deformation at SIFCON samples under the influence of bending loads. Both flexural and toughness properties determined by using samples with dimensions (100×100×400) mm at 28 and 56 days. The results were compared with those performed on conventional tests. An aspect ratio equal to 36.8 and three fiber content (3%, 5%, and 7%) . A conventional concrete mix was created as a reference for comparison. Bending strength and fresh concrete tests were performed. It is compared with the reference mixture. Results illustrated an improvement in flexural behaviour. It was found through the tests that the flexural strength of the mixture containing fiber percentage (7%) achieved highest value compared to the rest of the ratios used and compared with reference by 32.25 and 27.5% for ages 28 and 56, respectively.

1. Introduction

Concrete is one of the most frequently used building materials due to its high resistance to compression and good strength to external effects. But its resistance to tensile stresses is poor. Therefore, it is necessary to create concrete that has high tensile and compressive resistance in order for it to be well for structural uses. The fibers are combined into the concrete mix to enhance compressive and tensile strength. In 1968 AD, the first slurry infiltrated fibrous concrete (SIFCON) was produced in the USA either by putting the fibers into the concrete inside the mold before adding mortar on top of it, allowing the mortar to permeate the network of fibers, or by adding the mortar first to the mold before adding the fibers by immersing them within the mortar. Adding fibers to concrete is not a new concept, and it has been used to create Fiber Reinforced Concrete (FRC) with a very low fiber content of no more than 2% of the concrete volume. Because in this way the fibers can be added to the concrete during mixing. When the percentage of fibers exceeds 2%, it leads to agglomeration, isolation, and

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inhomogeneity within the mixture in a good way. This results in a weak porosity concrete. The high percentage of fibers in SIFCON concrete also results in the production of concrete with high tensile strength and good ductility. Using 5% from hooked steel fibers with SIFCON mix under two points loading showed highest flexural resistance (Abdul Rahim, Ghazaly, Ragunathan, & Shahidan, 2014). Slurry of SIFCON content of cement, fly ash, granular blast furnace slag and silica fume to produce SIFCON beams achieved 134% increase in hardness, a 33% increase of compressive strength, and a 179% increase in bending strength compared to regular concrete (Elnono, Salem, Farahat, & Elzanaty, 2009). Fiber reinforced concrete (FRC) had a higher flexural strength than concrete without fibers, especially when the percentage of fibers was increased, as well as when the aspect ratio was increased. Also, the adhesion between concrete and plastic fibers was strong (Meza & Siddique, 2019). Using hybrid fiber (2.5% fine steel fiber plus 6% bent end steel fiber) with SIFCON mixture achieved increasing in compressive, tensile, and impact strengths. In addition to , it achieved after being subjected to freeze-thaw cycles in comparison to specimens containing hook fiber (Ali & Riyadh, 2018). Effect of adding fibers produced by cutting plastic beverage bottles as fiber into concrete at small percentages of concrete volume (0.1 and 0.2%) improves its compressive strength (11.28; 14.28%) and flexural strength (46.15-64.61%) (Al-Hadithi, 2008) . Concrete mixed with plastic particles that were replaced partially proportioned with fine aggregate up to 20% reduced the strength properties (Batayneh, Marie, & Asi, 2007). Addition of waste plastic fibers (WPFs) to concrete increased compressive strength due to the fibers' increased interlocking within the matrix and reduced cracking development during loading compared to reference concrete. Values of compressive and flexural strengths had improved due to using of waste fibers (1%). As mentioned above, all conclusions about the improvement of compressive strength and flexural strength were obtained from the addition of waste plastic fibers in proportions not exceeding 2% (Abed, Al-Hadithi, & Mohammed, 2018) .

2. Experimental Work

2.1 Materials

2.1.1 Cement

Type I of cement was used in this study and its properties are the same as Iraqi standard. No.5 / 2019.

2.1.2 Fine Aggregate

In order to EFNARC specification (EFNARC, 2002)and Iraqi specification No.45/1984 Zone2 (Iraq No.(45), 1984) natural sand at size was 1.18 mm was used. Sand tests were performed at the Engineering Laboratory, in the University of Anbar, as illustrated in **Tables 1**, 2 and **Fig. 1**.

Table 1- Physical properties of fine aggregate

Test	Results	Iraqi specification No.(45)for1984
Sulphate content So_3%	0.12%	(0.5% maximum)
Specific gravity	2.543	
Absorption%	0.11%	
Fineness Modulus%	2.9	

Table 2- Grading of fine aggregate

No	Size of sieve, (mm)	Cumulative pass, (%)	Iraqi specification No. (45) for1984, (zone2)
1	10	100	100
2	4.75	97.7	100-90
3	2.36	83.43	100-75
4	1.18	71.38	90-55
5	0.6	54.3	59-35
6	0.3	15.5	30-8
7	0.15	2.3	10-0

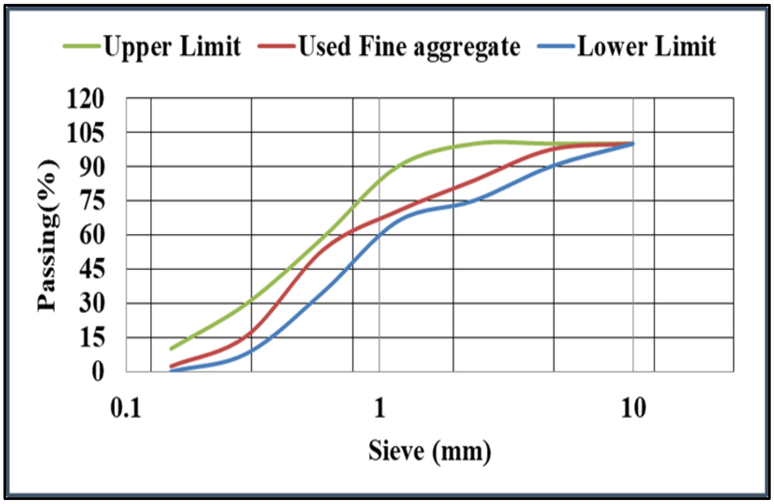


Fig. 1 Grading result of fine aggregate

2.1.3 Coarse Aggregate

Crushed stone of maximum size (10) mm was used. It complies with the Iraqi Standard No. 45/1984 (Iraq No.(45), 1984)as shown in **Tables 3** , **4** and **Fig. 2**.

Table 3-Physical properties of coarse aggregate

Test	Results	Iraqi specification No.(45)for1984
Sulphate content	0.035%	(0.1% maximum)
Specific gravity	2.64	
Absorption	0.83%	
% Passing 0.075mm sieve	1%	(2% maximum)

Table 4- Sieve analysis of course aggregate

No	Size of sieve ,(mm)	Cumulative pass,(%)	Iraqi specification No.(45) for1984
1	20	100	100
2	14	100	90-100
3	10	81.7	50-85
4	5	8	0-10

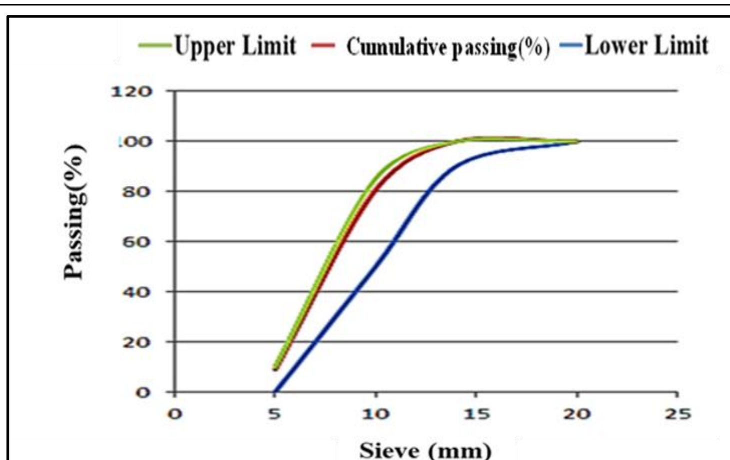


Fig. 2 Grading result of coarse aggregate

2.1.4 Water

Ordinary water from the tap of the main water network was used.

2.1.5 Fibers

Waste plastic fibers (WPF) were used from cutting manually for soft drink bottle. Its characteristics are illustrating in **Table 5**.

Table 5- Characteristics of WPF

Type of Fiber	Water Absorption %	Density (kg/m^3)	Aspect ratio A_r	Width (mm)	Length (mm)	Thickness (mm)	Colour	Tensile strength (MPa)
Plastic fibers (WPF)	0	1285	36.8	1.8	30	0.29	Crystalline &Green	101

2.1.6 Admixtures

In this study, super plasticizer (Viscocrete type 5930) was used. Properties from the manufacture company are illustrate in **Table 6**.

Table 6- Properties of superplastizer (Viscocrete type 5930)

Basis	Exterior	Density	Max.dose
Modified aqueous solution Polycarboxylate	Turbid liquid	1.095 kg/lt. (ASTMC494)	2 % litre by weight of cement

2.2 Mixing Proportions and Tests on Fresh Properties of SIFCON

Many attempts (mini slump flow) were performed to obtain slurries with the right flow ability to penetrate waste plastic fiber network without large voids in the specimen or separation of components. W/C was changed and percent of superplasticizer to binder as illustrated in **Table 7**. SIFCON differs from reference concrete (FRC) is that fresh SIFCON properties are difficult to its capacity to be well laid. Matrix of SIFCON should be fluid and flow able sufficient to pass during fiber's network. Viscosity, and flow ability are key workability properties that must be carefully controlled for successful manufacturing of SIFCON concrete. A mini-slump was used, according to EFNARC (EFNARC, 2002), to locate characteristics of the slurry. Test describes the mortar's fluidity and strength to separation. Bottom diameter, upper diameter, and height of test device used were (100, 70, 60) mm, respectively. Also, for SIFCON mortar, a spread diameter in the range of 240–260 mm is required. Details of this test can be found in EFNARC (EFNARC, 2002). Fresh property results for SIFCON mortar are shown in **Table 7**.

Table 7- Trial mixture for slurry of SIFCON

Dosage of super plasticizer, (%) by weight of cement	w/b ratio	penetration of slurry during dense plastic fiber
2	0.3	*Poor penetration
1.5	0.3	*Poor penetration
1	0.3	**Excellent penetration

*** Poor penetration: mini slump flow diameters test is high, larger than (240-260) mm.**

**** Excellent penetration: diameters of the mini slump flow test inside rang from (240 to 260) mm.**

After conducting several experiments, the ideal slurry ratio for SIFCON production was achieved as shown in **Tables 8** and **9**. Three types of fiber content of waste plastic fibers were used in this research, which are (3%, 5%, and 7%), and each mixture was labeled according to the percentage of fibers, as shown in the **Table 10**.

- Water to binder equal 0.3
- Ratio of superplasticizer to the weight of the binder is 1% .
- Cement and sand ratio 1:1

Table 8- Mixing Content of SIFCON

Type of Mixture	Mixture Design				
	Ordinary cement (Kg/m^3)	**Sand (Kg/m^3)**	**Plastic Fiber %**	**w/c ratio**	**SP (Kg/m^3)**
SIFCON	1005.2	1005.2	3% 5% 7%	0.3	10.052

Table 9- Reference Mix Content

Material	Cement (Kg/m^3)	Sand (Kg/m^3)	Gravel (Kg/m^3)	Water (Kg/m^3)
	592	592	888	236.8

Table 10- General details and variable of the tested specimens

Specimen symbol	Fiber percentage %	Aspect ratio
R0	0	-
S3	3	36.8
S5	5	36.8
S7	7	36.8

2.3 Preparing, Casting, and Curing of SIFCON

In the first stage of preparing SIFCON samples, the waste plastic fibers were placed in the molds in the form of layers, in the order of three layers. The dimensions of the sample were (100 × 100 × 400)mm, where the first layer of fibers was placed, which is one-third of the volumetric percentage of the sample. Then a slurry was poured over it, which had to be flow able enough to permeate through the dense fibers. While, second layer of fibers and mortar is poured over it, and then the third layer of fibers and mortar is poured over it, thus making the mold complete. Layers are not subjected to vibration for percentages less than (6%). As for the layers (7%), they needed to be vibration for a period of (6–10) seconds by means of a vibrating table in order to ensure the penetration of the slurry into the fiber network. The weight of the waste plastic fibers that will be put in the mold depends on the dimensions of the mold that will be used, required content of fiber, and density of waste plastic fibers themselves. After completing casting specimens were placed in the laboratory for 24 hours. After that it was disassembled, labeled, and immersed in the treatment basin (water tank) for a period of 28 and 56 days. See **Fig. 3**.

(a)Put fibers in molds **(b) pouring mortar on fibers** **(c) SIFCON specimens**

Fig .3 (a) ,(b) , and (c) Casting of SIFCON Mixtures

2.4. Hardened Properties Testing of SIFCON

2.4.1. Flexural Strength Test

This test was carried out in accordance with ASTM-C1609 (ASTM C1609M –12, 2012) ,with a specimen size of 100 x 100 x 400 mm. The specimens were tested by a computer-controlled by servo hydraulic universal machine at a constant deformations rate of approximately 0.5 mm/s. Specimens were tested at 28 and 56days, with an average of three specimens used for every test. Flexural resistance of samples is calculated using the equation below:

$$fr = PL/bd^2 \qquad (1)$$

Where:

fr: modulus of rupture, MPa.

P: maximum load, N.

L: Span length, 300 mm.

b: width of specimen, mm.

d: depth of specimen, mm.

2.4.2. Flexural toughness and The Load Deflection curve

Toughness refers to capacity of a specimen to absorb energy. That is equal to the area under the load-deflection curve (Aziz, 2014). Saved data from flexural calculated was employed to determine toughness meet with ASTM-C1609 (ASTM C1609M –12, 2012) .

3. Results and Discussion

3.1.1. Flexural Strength

Table 11 and **Fig. 4** show the flexural strength results of reference and SIFCON mixes at 28 and 56 days. shows the difference between the reference mixture and SIFCON, where three samples of each mixture were tested and averaged.

Table 11-Flexural strength for investigated mixture at different ages (MPa)

Type of Mixture	Flexural Strength (MPa) at 28 day	Flexural Strength (MPa) at 56 day day	Compressive Strength (Mpa) at 28
R0	3.72	4.2	43.26
S3	4.13	5.152	47.29
S5	4.3	5.214	45.4
S7	4.92	5.356	39.84

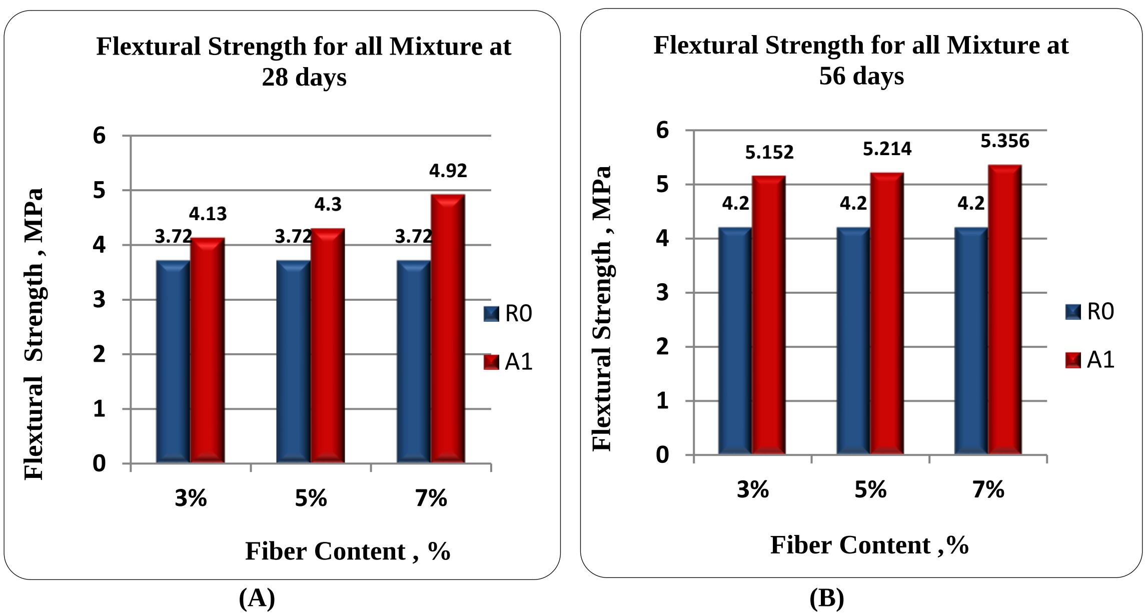
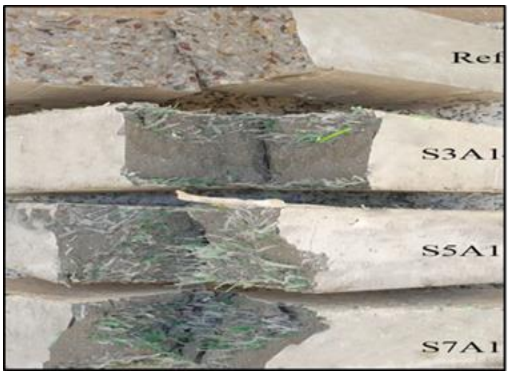


Fig. 4 (A) and (B) Flexural strength in reference and SIFCON mixtures

3.1. Hardened Properties

Flexural strength of (S3) was found to be 11 and 22,6% greater than that of the reference mixture (R0) in each age of (28 , 56) days respectively, through flexural tests. On the other side, the flexural strength of the (S5) mixture was 15.59 and 24.14% for ages 28 and 56 days, respectively, which was greater than reference mixture (R0). Flexural strength of (S7) mixture was 32.25 and 27.5% greater for ages 28 and 56 days ,respectively, than that of the reference mixture (R0). **Fig. 5** shows the fracture pattern of the SIFCON sample, showing a high proportion of waste plastic fiber entanglement and high affinity. The prisms did not separate after the flexural test, but they were separated by beating in order, to preview the distribution of fibers within the prism.

The higher values of flexural strength in SIFCON mixtures compared to the reference mixture are due to the high percentage of plastic fibers. where it was observed that flexural resistance improved with increase of percentage of plastic fibers in mixtures, due to of bond between the concrete paste and the plastic fibers and the impediment to the generation of cracks after the occurrence of the first crack. whereas the increase in flexural strength as the percentage of plastic fibers increases results from the closeness and decrease in distances between the fibers, which impede the formation of cracks except at high loads. This does not occur in the reference mixture, where the failure is brittle, in addition to impeding the development of cracks generated after these loads, which eventually lead to ductile failure. On the other hand Particularly when adding fibers (3% and 5%), the increased of fibers in SIFCON achieved increasing in compressive strength in comparison to reference mix because the slurry effectively penetrated the fiber network, reducing porosity and increasing the bonding between fibers and cement paste. The existing fibers will try to prevent the spread of microcracks when they begin develop, which causes the cracks to move in a zigzagging path and therefore need more energy to proceed, improving the ability to resist external stresses (Alcan & Bingöl, 2019). Because the difficulty of slurry permeability through fiber network and high percent of air voids, which results bonding weakness between the cement paste and fibers, the compressive strength will decrease when using a fiber ratio of 7% in SIFCON compared to the reference mixture. Microcracks will spread quickly as a result, which decreases compressive strength (Deepesh & Jayant, 2016).



(a) Fibers Distribution

(b) Cracks Pattern

Fig. 5 (a) , (b) Distribution of Plastic Fibers and Cracks Pattern of Tested Samples

3.2.2. Flexural Toughness

Results of the flexural strength tests using a computer-controlled by hydraulic universal machine at a constant deformations rate of approximately 0.5 mm/sec and using specimens with dimensions of (100 × 100 × 400) mm, with three specimens per mixture, and taking the average of the three readings, showed ,at 56 days . By drawing the load-deformation curve, it was found that the toughness values are as shown in the **Table 12** and represented graphically in the **Fig. 6**, after calculating area under load deformation curve.

Table 12- Flexural toughness investigated mixture at age of 56 days

Type of Mixtures	Flexural Toughness (KN.mm) at Deflection (3mm) of the age 56 days	Increase%	Decrease%
R0	3.25	-	-
S3	13.99	330%	-
S5	21.35	557%	-
S7	26.86	726%	-

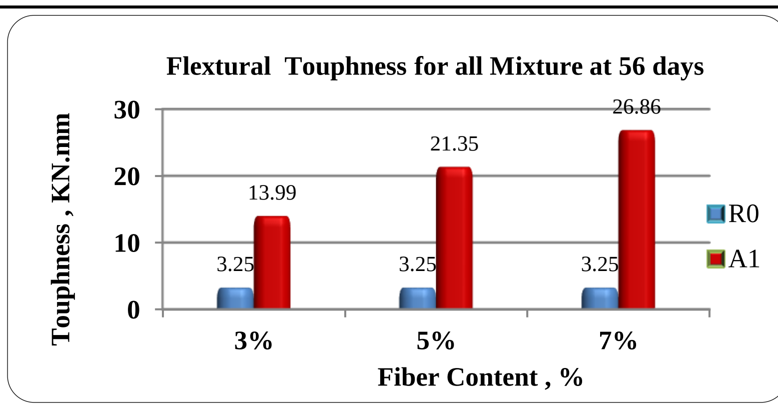
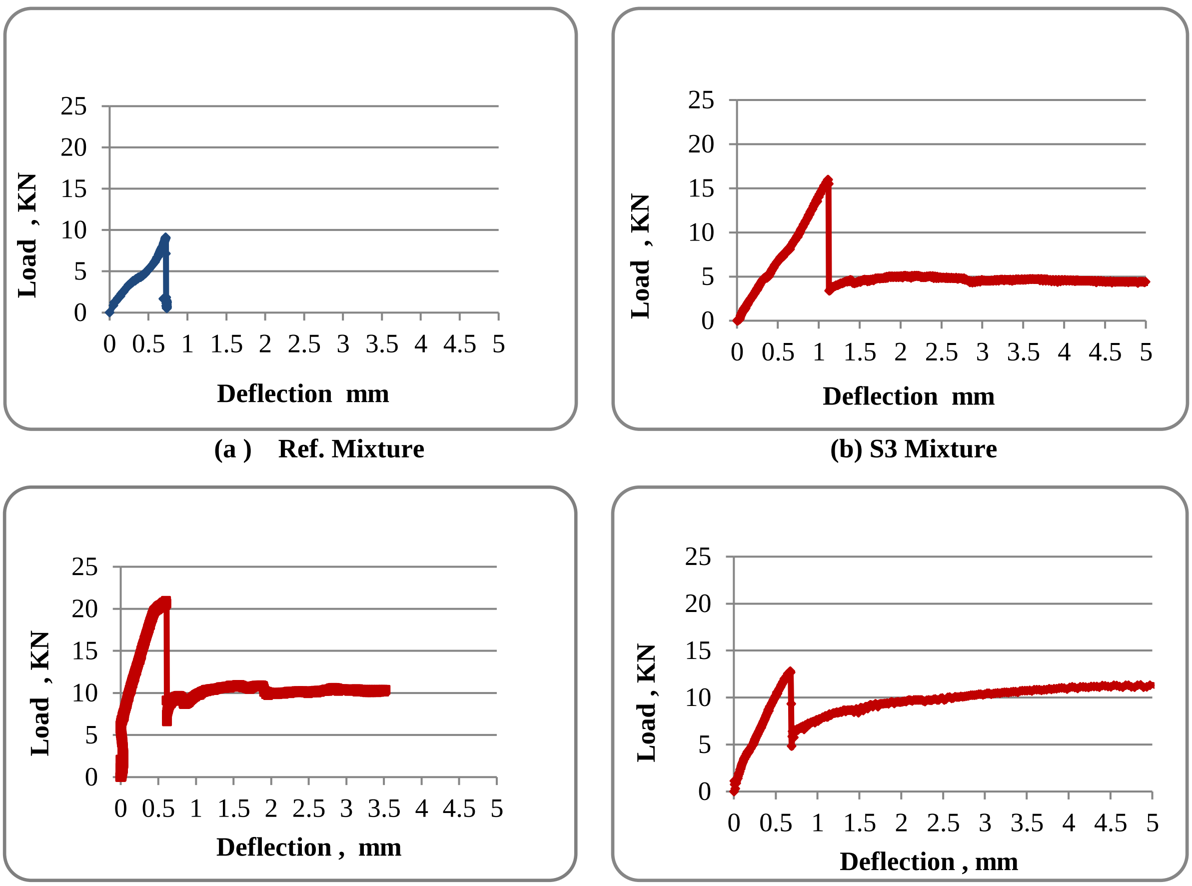


Fig. 6 Flexural toughness

Results illustrated that an improvement in the toughness values of SIFCON mixtures compared to the reference mixture in general, where the mixtures (S3, S5, S7) recorded an improvement in toughness compared to reference mixture (R0) by 330%, 557%, and 726%, respectively, at 56 days of age. This is mathematically due to the increase in area below load-deformation curve as volumetric ratio of fibers in mixture increases compared to the reference mixture, and technically due to the presence of fibers that act as bridges to transfer energy between the two ends of the cracks. Toughness is correspond with ability of the concrete to absorb energy after the formation of cracks, and the fibers work with the concrete matrix to impede the development of cracks and transform the failure from a brittle failure as in the reference mixture to a ductile failure. Thus increasing area under load-deformation curve. **Fig. 7** show load-deformation curve for SIFCON and reference (R0) mixtures.



(a) Ref. Mixture **(b) S3 Mixture**

(c) S5 Mixture **(d) S7 Mixture**

Fig. 7 Load-deformation curves of SIFCON mixtures and reference mixture: (a)Reference mixture, (b) ,(c) , and (d) SIFCON mixtures.

From **Fig. 7** of the load-deformation curves, we notice a gradual rise of the load, but at a certain load, a sudden collapse to a certain load point, then the return to the load resistance, then the gradual collapse, so that the failure after this point is a ductile failure. This is due to the fact that the SIFCON production mechanism used in this research used three layers of fiber. The first layer of fibers put on the floor of the mold, then mortar, then the second layer of fibers on top of the mortar, then mortar again, then the third layer of fibers, then mortar. as a result of the light weight of the plastic waste fibers, the elongated lamellar shape, and the softness of the slurry to the extent that it prevents nesting between the fibers. All this led to the mixing of the second layer with the third layer, which was a floating layer between two layers of mortar. As a result, when the load was applied, the first layer of mortar resisted the load up to a certain limit. Then a sudden collapse occurred in the mortar layer that formed between the first layer of fibers and between the second and third layers of fibers, then it gradually resumed resisting the load and ductile failure. This leads to a set of conclusions regarding the mechanism of SIFCON production using waste plastic fibers and determining the best proportion of waste plastic fibers, which will be mentioned later.

4. Conclusions

1- The increased of waste plastic fibers due to increasing of flexural strength. The S7 mixture was therefore the best mixture in terms of flexural strength. This improvement is highly dependent on the method used to create the SIFCON mixture in terms of the number of fiber layers and the distribution of fibers within the sample. in addition to the properties of the mortar used.

2- By increasing the proportion of waste plastic fibers, the toughness increases. Therefore, the SIFCON mixture at 7% was the best mixture in terms of toughness. It recorded an increase in toughness by a percentage of 726% with respect to reference mixture at 56 days of age.

3- For purpose of producing SIFCON using plastic waste fibers better in future, the viscosity of the slurry must be increased by using viscosity additives such as silica fume or other additives as a partial substitute for cement (to decrease the spread diameter of mini slump), which can be controlled by an appropriate dose of superplasticizer. Thus, it will help in the better spreading of the plastic waste fibers because of their light weight and elongated lamellar shape, and it will prevent the fibers from rising to the top because of their shape and light weight.

4- Production of high-performance concrete using waste plastic fibers without separation or nesting, with a significant improvement in flexural properties, leads to the possibility of producing SIFCON using it.

5. References

Abdul Rahim, M., Ghazaly, Z. M., Ragunathan, S., & Shahidan, S. (2014). *The Behaviours Of Steel Fiber As Main Reinfocement In High Performance Slurry Infiltrated Fiber Reinforced Concrete* (Vol. 594): Trans Tech Publ.

Abed, A., Al-Hadithi, A., & Mohammed, A. S. (2018). *The effects of adding waste plastic fibers on some properties of roller compacted concrete.* Paper presented at the MATEC Web of Conferences.

Alcan, H. G., & Bingöl, A. F. (2019). Examining SIFCON's mechanical behaviors according to different fiber and matrix phase. *Iranian Journal of Science and Technology, Transactions of Civil Engineering, 43*, 501-507.

Al-Hadithi, A. I. (2008). Some properties of concrete using waste plastic fiber with a very small percentages.

Ali, A. S., & Riyadh, Z. (2018). Experimental and Numerical Study on the Effects of Size and type of Steel Fibers on the (SIFCON) Concrete Specimens. *International Journal of Applied Engineering Research, 13*(2), 1344-1353.

ASTM C1609M–12, (2012). " Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third Point Loading)" American Society for Testing and Material International.

Aziz Ibrahim, (2014). ″ Scientific Research, Methodology, Form, Rules, Stages″. page 41,42(Arabic)

Batayneh, M., Marie, I., & Asi, I. (2007). Use of selected waste materials in concrete mixes. *Waste management, 27*(12), 1870-1876.

Deepesh, P., & Jayant, K. (2016). Study of mechanical and durability properties of SIFCON by partial replacement of cement with fly ash as defined by an experimental based approach. *International Journal for Innovative Research in Science & Technology, 5*(5), 8568-8574.

EFNARC, S. (2002). Guidelines for Self-Compacting Concrete, European Federation for Specialist Construction Chemicals and Concrete Systems, Norfolk, UK. *English ed., February*.

Elnono, M. A., Salem, H. M., Farahat, A. M., & Elzanaty, A. H. (2009). Use of slurry infiltrated fiber concrete in reinforced concrete corner connections subjected to opening moments. *Journal of Advanced Concrete Technology, 7*(1), 51-59.

Iraqi Standard No. 5. 2019. Central Organization for Standardization and Quality Control, 2019 *Portland Cement. Baghdad, Iraq*.

Iraq Standard specification (IQS) No.45 (1984)."Natural sources of aggregate used in building and concrete" ,Baghdad 13p.

Meza, A., & Siddique, S. (2019). Effect of aspect ratio and dosage on the flexural response of FRC with recycled fiber. *Construction and Building Materials, 213*, 286-291.

Some concrete properties of concrete using waste plastic fiber with a very small percentage "Al-hadithi A.I.A" second hallab conference,2008.