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Research Article

Ihab S. Saleh*, Muthana Sh. Mahdi and Mohammed F. Ojaimi

Destructive and nondestructive tests formulation for concrete containing polyolefin fibers

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Abstract: Polyolefin fiber is a new type of fiber that was used in concrete to improve some of the poor properties of concrete including; tensile strength, ductility, and fracture energy. In this research, the contribution of Polyolefin fiber in improving the properties of hardened concrete was examined by adding polyolefin fibers to mix with different fiber content. The polypropylene fibers were added as a ratio of 0.5, 0.75, 1.0, 1.5, and 2% of concrete volume. Destructive and non-destructive tests were carried out: slump, compression, splitting, and bending, Schmidt Hammer, and ultrasonic pulse velocity tests. The results showed that, as the polyolefin fiber content increases, the workability of concrete reduces dramatically. The experimental findings demonstrate that the concrete tensile strength and ductility were improved by a small improvement in overall compressive strength. The results show that the compressive strength increased gradually with the increase in fiber content of up to 1.5%, and then, the compressive strength starts to decrease. However, the tensile strength increases continuously with the fiber content increasing. A good relationship was obtained between the destructive and nondestructive tests.

Keywords: polyolefin fibers, nondestructive tests, flexural strength, fiber-reinforced concrete

1 Introduction

Concrete is a relatively brittle material; therefore, the addition of fibers to concrete makes it more ductile, homogenous, and isotropic [1]. Variable fibers, such as carbon, alcohol polyvinyl, steel and glass fibers, will potentially increase strength due to strong modulation, whereas low resistance fibers like polypropylene, nylon, and acrylic increase the ductility and consequently, minimize cracking [2]. In the construction of the building, the mechanical properties of concrete have been improved by fiber-reinforced concrete. Workability, strength of compression, tension [3–5] polyethylene, and polypropylene are commonly used polyolefins and the fastest growing class of polymers, due to high development and low manufacturing costs in relation to plastics. Polyolefin fibers have wide usage in modern manufacturing. Low cost, good chemical tolerance, high resistance, and sustainability have been used extensively. Polyolefin fiber with a high tensile resistance and excellent corrosion resistance is typically solid [6,7]. Polyolefin-reinforced concrete has excellent post-cracking behavior. The total costs of the material can be greatly reduced by plastic fibers and the corrosion issues of SF can be prevented. In addition, several carbon footprint reductions have also been recorded as opposed to steel production [17]. Polyolefin fibers have been attractive to scientists in the concrete industries. Studies to eliminate stainless steel corrosion are also underway [8–13]. Based on the major advantages such as increasing structural strength, polyolefin fibers are commonly used [14,15]. Polyolefin fibers, which have no water reactions, are less weight than steel fibers. Despite steel degradation and cracks, polyolefin fiber-reinforced concrete exhibits stronger performance [16]. The structure and rugged construction of Polyolefin fibers improve the bonding properties with concrete. Reinforced concrete polyolefin fiber also has a higher bending power. Researchers have conducted several years of laboratory research on certain of the following studies, which include the advantages of polyolefin fibers in ordinary concrete, lightweight concrete, foamed concrete,

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*** Corresponding author: Ihab S. Saleh,** Civil Engineering Department, College of Engineering, University of Basrah, Basrah, Iraq, e-mail: ihab.sabri@uobasrah.edu.iq
Muthana Sh. Mahdi: Civil Engineering Department, College of Engineering, University of Basrah, Basrah, Iraq, e-mail: muthana.shaker@uobasrah.edu.iq
Mohammed F. Ojaimi: Civil Engineering Department, College of Engineering, University of Basrah, Basrah, Iraq, e-mail: mohammed.ojaimi@uobasrah.edu.iq

and highly efficient concrete. Balaguru and Shah [17] have reported that, in general, there has been a small influence on compressive strength where the steel-fiber in the concrete is added, although in some cases others feel that the compressive strength has increased up to a maximum of 25%. Furthermore, significant improvements are normally found in tension and toughness. Furlan and De Hanai [18] have stated that the characteristics of concrete are highly affected when a large volume of fibers is added. At the same time, the authors have found that the tensile strength of concrete is not significantly modified when the volume of fibers added is lower than 2%. Meddah and Bencheikh [19] The feasibility of adding by-product fiber from metallic and polypropylene as the strengthening of standard concrete was addressed. The effects on mechanical properties of fiber-reinforced concrete have been experimentally studied by integrating different waste metallic fibers and waste polypropylene fibers (WPFs). The effect of the compressive, flexural strength, and hardness of reinforced fibers by the shape, volume, and length of waste fibers are evaluated; the results showed that the WPF diminished compressive strength, especially when using long, high-volume fibers.

2 Experimental program

The research experimental procedure is intended for fresh and reinforced concrete. The slump test is used to determine concrete workability. Tests for hardened concrete include preparation and evaluation of 150 mm × 150 mm × 150 mm concrete cubes, preparation, and measuring of concrete Prism of 100 mm × 100 mm × 350 mm as well as preparation and casting of 300 mm×150 mm concrete cylinders. The polyolefin fibers used in this study are in volume proportions of 0.5, 0.75, 1.0, 1.5, and 2.0% of the concrete volume.

2.1 Materials

Depending on the location, convenience, affordability, and availability, the following materials such as cement and components are used:

2.1.1 Cement

Ordinary Portland cement conforms to ASTM C150-15 [20] specification requirements and was used in this study. The chemical composition and physical test results of the cement used are listed in Table 1.

2.1.2 Fine aggregate

Natural sand was used in the city of Basrah in the Sanam Mountain zone. Table 2 displays fine aggregate grading and ASTM C33-13 limits [21], and Table 3 shows the physical and chemical test results of the used fine aggregate.

Table 1: Chemical composition and physical test results of the cement used

Physical test results			
Test	**Unit**	**Test result**	**ASTM C 150 – 15 Limits O.P.C – Type I**
Initial setting time	Minute	139	45 –375
Compressive strength	MPa		
3 Days age		15.7	12 min
7 Days age		23.6	19 min

Chemical test results			
	Test	**Test result**	**ASTM C 150 – 15 Limits O.P.C – Type I**
Ratio%	SiO_2	18.5	—
	Al_2O_3	4.1	—
	Fe_2O_3	2.7	—
	CaO	46.9	—
	MgO	3.66	6 max.
	C_3A	3.3	—
	SO_3	2.25	3.0 max.
L.O.I %		2.75	3 max.
I.R %		0.52	0.75 max.

Table 2: Grading of the fine aggregate used

Sieve size (mm)	**Percent passing**	
	Fine aggregate	**Limits of ASTM C33 [21]**
9.5	100	100
4.75	98	95–100
2.36	85	80–100
1.18	66	50–85
0.6	40	25–60
0.3	13	5–30
0.15	2	0–10
0.075	1.5	0–3

Table 3: Properties of the fine aggregate

Test	Result
Fineness modulus	2.91
Specific gravity	2.65
Sulfate content (SO_3), (%)	0.33
Absorption, (%)	1.2
Loose bulk density (kg/m^3)	1,645

2.1.3 Coarse aggregate

Crushed gravel with size (19–4.75) mm was used from the area of the Sanam mountains in Basrah town. Table 4 shows coarse aggregate grading complies with ASTM C33-13 [21]. The Specific gravity, content of sulfate, chloride, and absorption of the coarse aggregate are described in Table 5.

2.1.4 Polyolefin fibers

Polyolefin fibers consist mostly of macromolecules and saturated aliphatic (Figure 1). A polyolefin is classified as a produced fiber in which any synthetic long-chain polymer composed of a mass of ethene, propene, or other olefin units at least 85% is formed by the fiber former. In this study, SikaFiber® Force-60 was used. Table 6 displays the SikaFiber® Force-60 technical info.

Table 4: Grading of the coarse aggregate used

	Percent passing	
Sieve size, mm	Coarse aggregate used	Limits of ASTM C33-13 [21]
25	100	100
19	92	90–100
9.5	39	20–55
4.75	4	0–10
2.36	1	0–5
0.075	0.4	0–1

Table 5: Physical and chemical test results of the coarse aggregate used

Test	Result
Specific gravity	2.61
Sulfate content (SO_3)	0.083%
Chloride content (Cl)	0.097%
Absorption	0.85%
Loose bulk density (kg/m^3)	1,588

Figure 1: Polyolefin Fiber – SikaFiber® Force-60.

2.1.5 Water

For mixing and curing of concrete, ordinary drinking water was used.

2.1.6 Superplasticizer

Superplasticizer (HWRA) based on polycarboxylic ether is used for manufacture of high-performance concrete. Sika F-180g is one of the latest copolymers in the generation. The ASTM C494(2004) [22], Type A, and Type F are compliant.

2.2 Mix proportions and concrete properties

In this study, there are only one mix proportion which was used with different polyolefin fiber content as

Table 6: Technical data of SikaFiber® Force-60

Physical properties	Test results
Density	910 kg/m^3
Dimension	Length ~60 mm, equivalent diameter ~0,84 mm
Tensile strength	~430 MPa
Modulus of elasticity in tension	6 GPa

summarized in Table 7, in order to clarify the effect of fiber content on the concrete workability; constant water cement ration (w/c) of 0.39 was used. For the control mix (zero fiber content), the slump and compressive strength target was 200 mm and 40 MPa, respectively. Superplasticizer was used to achieved goals of slump target (Figure 2).

3 Test method

The hardened concrete compressive strength test was conducted on the basis of the BS EN 12390-3:2009 model system [23], on the cubic component with dimensions 150 mm × 150 mm × 150 mm. Molded casting reveals in Figure 3. After 7 and 28 days of storage in water, six compressive specimens were produced for each blend. Processing samples were carried out in pool water. The employed machine for determination of the compressive strength had a capacity of 2,000 kN. Concrete Prism with dimensions of 100 mm × 100 mm × 350 mm and the test was conducted in accordance with the standard ASTM C78/C78M method [24] to assess the flexural strength of hardened concrete. After 28 days of specimen care, the examination was performed. The splitting power tensile was calculated in the cylindrical specimens with size 300 to 150 mm following 28 days of storage in water, according to standard ASTM C496/C496M method [25] on cylindrical specimens with dimensions of 300 × 150 mm after 28 days of storage in water.

Table 7: Mix proportion and polyolefin fiber percentage

Mix No.	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Cement (kg/m^3)	Fiber (kg/m^3)	Fiber (%)
1	1,112	667	445	0	0
2	1,112	667	445	4.45	0.5
3	1,112	667	445	6.825	0.75
4	1,112	667	445	9.1	1
5	1,112	667	445	13.65	1.5
6	1,112	667	445	18.2	2

Figure 2: Polyolefin fiber in concrete mix – SikaFiber® Force-6.

Figure 3: Test specimen molds.

The rebound number was measured of the 150 mm cube specimens using Schmidt Hammer according to ASTM C 805-02 [26]. The ultrasonic pulse velocities of the concrete cubes were measured according to ASTM C597-02 [27] using transducers with frequency 54 kHz, as shown in Figure 4.

4 Results and discussion

This study leads to the following results:

4.1 Fresh concrete

Table 8 shows the new concrete characteristics for each mixture form (slump value). The results demonstrate clearly that the concrete containing polypropylene fibers, in comparison to standard concrete, has lower slump values. The slump decreased as the fiber content rises as shown in Figure 5. The resistance strength of concrete containing polyolefin fiber can be the cause of this behavior.

Schmidt hammer test UPV test

Figure 4: Nondestructive tests.

Table 8: Slump of concrete mixes with different contents of polyolefin fibers

Specimen symbol	Polyolefin fiber %	Slump (mm)
F-1	0	220
B-2	0.5	200
B-3	0.75	170
B-1	1	140
B-4	1.5	100
B-5	2	80

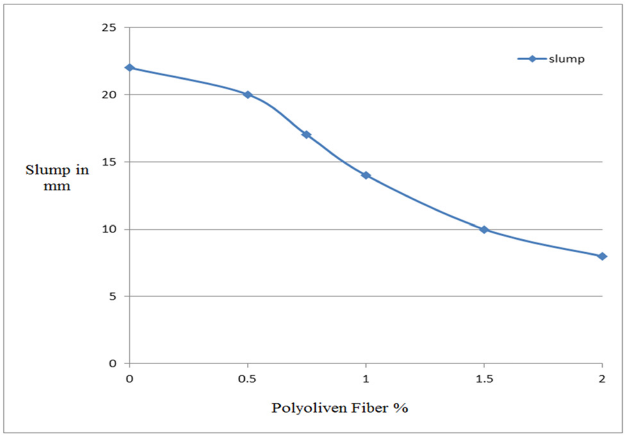

Figure 5: Slump of fresh concrete containing polyolefin percent in different mixes.

4.2 Hardened concrete

Destructive and non-destructive tests were carried out to establish the mechanical characteristics of the concrete that contains polyolefin fibers. Compressive power, bending strength, tensile cracking strength, Schmidt Hammer, and ultrasonic pulse speed (UPV) have been tested.

4.2.1 Compressive strength

For three samples per mixture, the compressive strength of the samples was measured at 7 and 28 days. Furthermore, the findings of concrete containing polyol Iven fiber were tested for non-destructive use. In the compressive strength of concrete with and without polyol Iven fibers, Schmitt Hummer and Ultrasound Testing are used. The overall compressive intensity results are shown in Table 9. The compressive strength of B-2, B-3, B-4, and B5 at 7 days shows increase in compressive strength when compared with plain concrete F-1. The ratios of increasing were 1.06, 1.09, 1.1, 1.05, and 1.01 respectively, while the ratios at 28 days were 1.11, 1.13, 1.28, 1.04 and 0.98 respectively, as shown in Figure 6.

4.2.2 Flexural strength

The tested concrete prisms at the age of 28 were performed on three samples from each concrete mix as in Table 10. Clearly, the increase in the polyolefin fiber content of the concrete results in a considerable increase in

Table 9: Compressive strength of concrete containing polyolefin fibers

Specimen symbol	Polyolefin fiber %	Compressive strength (MPa) at 7 days	Compressive strength (MPa) at 28 days
F-1	0	41.76	44.3
B-2	0.5	44.63	49.15
B-3	0.75	45.73	50.36
B-1	1	46.27	57.07
B-4	1.5	44.0	46.5
B-5	2	42.46	43.66

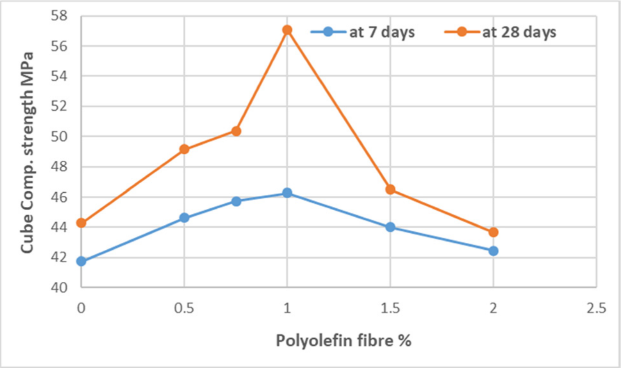

Figure 6: Compressive strength of concrete containing polyolefin % in different mixes.

Table 10: Effect of polyolefin fiber on flexural strength of concrete

Specimen symbol	Polyolefin fiber percent %	Flexural strength (MPa)
F-1	0	4.41
B-2	0.5	5.65
B-3	0.75	6.87
B-1	1	7.36
B-4	1.5	8.09
B-5	2	8.98

the bending power of cement, as shown in Figure 7. If the polyolefin concrete fiber content rises from 0 to 2%, the bending power rises by about 1.28, 1.56, 1.67, 1.83, and 2%. This may be due to the fiber–matrix interface, with better links and fewer air voids. The inclusion of polyolefin fibers in the concrete matrix seems to be a major barrier to the spread of fine cracks against the load. The delayed development of the primary crack that induces failure is responsible for this resistance. Moreover, polyolefin fibers, which results in increasing intensity, can reduce the tension levels accumulated around the cracks.

4.2.3 Splitting tensile strength

The strength of the concrete cylinder was measured on three samples of every concrete mix for 28 days, and the average results are given in Table 11. Figure 8 shows the results of dividing the tensile solidity of polyolefin fiber-containing concrete. The polyolefin fiber ratio rose from 0 to 2% to show a substantial improvement in the values of the fracturing power of tensile. The divisor intensity levels were 1.23, 1.38, 1.45, 1.51, and 1.66% more than standard concrete F-1, respectively. This conduct goes beyond polyolefin fibers' capacity to diminish the thick splits of the concrete. As splitting happened, fiber was transmitted from the matrix through the fibers, and hence, it eventually served the full load, which crossed the broken portions of the concrete matrix. The tension conversion enhanced the fiber-reinforced concrete's tensile strength and thereby strengthened the

Table 11: Effect of polyolefin fiber on splitting tensile strength

Specimen symbol	Polyolefin fiber %	Splitting tensile strength (MPa)
F-1	0	2.87
B-2	0.5	3.54
B-3	0.75	3.96
B-1	1	4.16
B-4	1.5	4.34
B-5	2	4.77

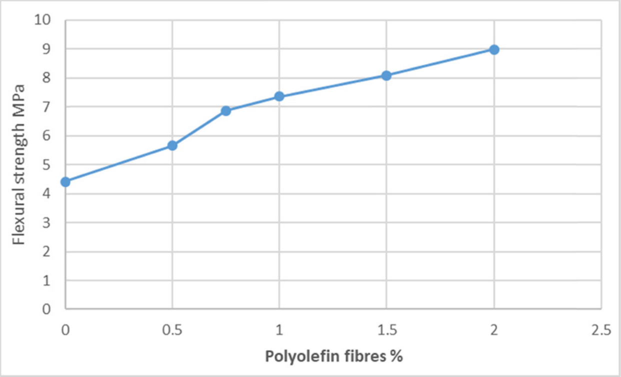

Figure 7: Flexural strength of concrete containing polyolefin % in different mixes.

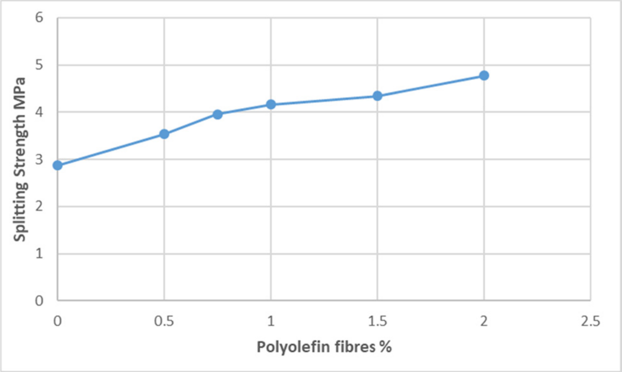

Figure 8: Splitting tensile strength of concrete containing polyolefin % in different mixes.

fracturing strength of the reinforced concrete on the unreinforced controller. Duration, dosage, and shape of polyolefin fiber are the principal effects on the splitting tensile power. Polyolefin fiber with scalloped shape may provide the best bond to the cementitious matrix and highly increase the splitting tensile strength.

4.2.4 Nondestructive tests

Table 12 shows that the rebound number and UPV have risen to 1% with the growth of fiber content, but after that it was reduced as the content of fiber. The polyolefin fiber tends to influence compressive power, rebound, and UPV number, as shown in Figures 9 and 10. When the polyolefin fibers reach 1.0%, the compressive resistance falls as a result of lower concrete cohesion and compacting difficulty of the concrete cubes. Depending on the earlier, the fiber quality of the prediction of compressive intensity is from 0 to 1%. Figure 11 reveals that the compressive strength of concrete and the ultrasonic pulse velocity of concrete are related regardless of the difference in fiber content; the increase in one is similarly reflected in an increase in the other. From this figure, the relationship between cube compressive strength (f_{cu}) and the ultrasonic pulse velocity (V) is obtained as given in equation (1).

$$f_{cu} = 0.0026V^2 - 26.254V^1 + 65{,}922. \tag{1}$$

Figure 12 describes the relationship between the rebound number and the compressive strength of the concrete with different fiber content. Test findings for mixtures made of concrete fiber containing polyolefin have shown a positive association between compressive strength and rebound number. The relationship between the cube compressive strength (f_{cu}) and the rebound number (RN) is determined as shown in the equation (2).

$$f_{cu} = 1.2681\text{RN}^2 - 92.009\text{RN} + 1{,}710. \tag{2}$$

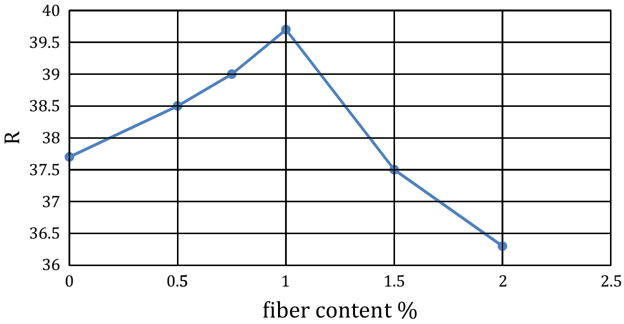

Figure 9: Rebound number and fibers content relationship.

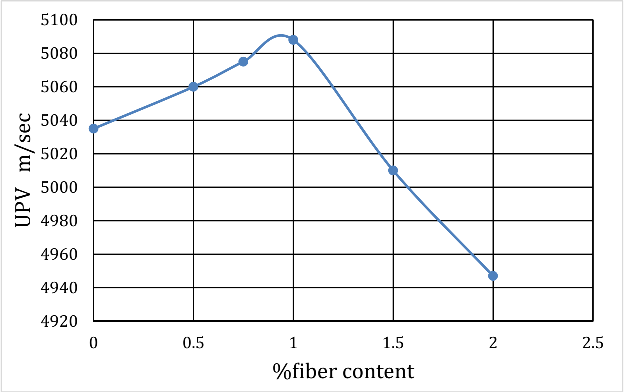

Figure 10: Ultrasonic pulse velocity and fibers content relationship.

5 Conclusions

The main objective of this study was improving the concrete mix properties by adding the olefin fibers in order to improving the compressive, flexural, and splitting strength. The practical tests in 7 and 28 day of samples ages were recorded. Consequently, and depending on the investigation finding in this study, it can be inferred that the slump in horn with poor workability and compaction of concrete decreases considerably as that of the polyolefin fibers increase. Polyolefin fibers have a little influence on

Table 12: Compressive strength and results of nondestructive tests at 28 days

Specimen symbol	Polyolefin fiber content (%)	Compressive strength (MPa)	Rebound number (RN)	Compressive strength estimated by RN (MPa)	UPV (m/s)	Compressive strength estimated by UPV (MPa)
F-1	0	44.3	37.7	44.5	5,035	57.1
B-2	0.5	49.15	38.3	47.1	5,060	50.4
B-3	0.75	50.36	39.3	53.5	5,075	49.2
B-1	1	57.07	39.7	56.8	5,088	46.5
B-4	1.5	46.5	37.5	43.8	5,050	44.3
B-5	2	43.66	36.3	41.9	4,947	43.7

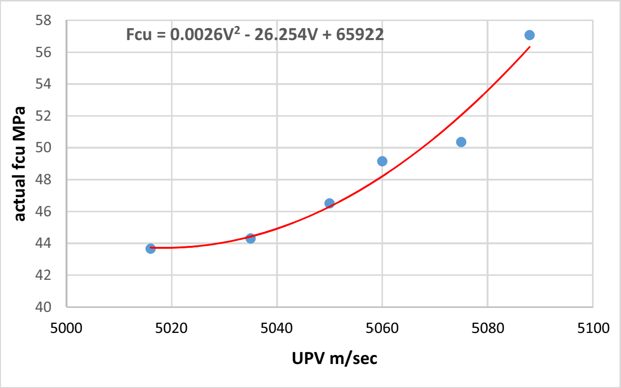

Figure 11: Ultrasonic pulse velocity and compressive strength relationship for concrete with fiber content from 0 to 1%.

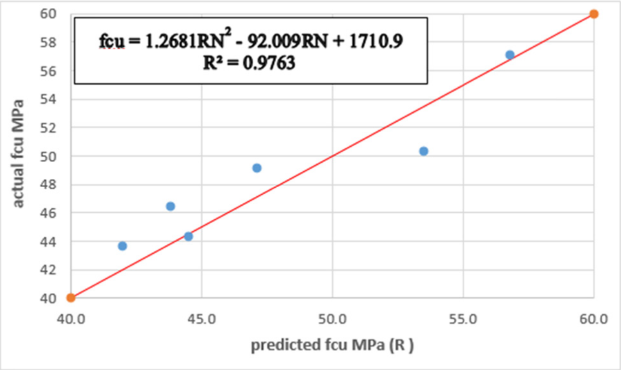

Figure 12: Rebound number and compressive strength relationship for concrete with fiber content from 0 to 1%.

the frequency of the compressive strength. This includes a drop in the compressive capacity of the polyolefin ratio to over 1.5%, while as the polypropylene fiber content rise up to 2%, the concrete ductility improved dramatically. The ultimate tensile strength was not increased by further improvement in polypropylene fibers (values of more than 1.5 vol.%), but much more ductile connections. The compressive strength of concrete mixtures that produce polyolefin fibers with rebound number and ultrasonic pulse velocity is well established. The effect of adding polyolefin fibers can be observed clearly by the considerable increase in the concrete compressive strength as well as the rising of concrete ductility which reflected on the flexural resisting of the concrete mix with fibers. The improving of the fresh and hardened concrete can be demonstrated as the result of fiber's action which increases the bond between the concrete mix contents; consequently, the concrete shows better properties.

Conflict of interest: Authors state no conflict of interest.

References

[1] ACI Committee 544. Measurements of properties of fiber reinforced concrete. ACI Mater J. 1988;85(6):583–93.
[2] Pakravan HR, Latifi M, Jamshidi M. Hybrid short fiber reinforcement system in concrete: A review. Constr Build Mater. 2017;142:280–94.
[3] Konig G. New concepts for high performance concrete with improved ductility. proceedings of the 12th FIP Congress on Challenges for Concrete in the Next Millennium. Netherlands: 1998. p. 49–53.
[4] Ramezanianpour AA, Najimi M, Pourkhorshidi A. The role of polypropylene fibers on concrete properties. First Disaster Management Symposium. University of Tehran; 2006. p. 542–9.
[5] Breitenbucher R. High strength concrete C 105 with increased fiber resistance due to polypropylene fibers. 4th International Symposium on the Utilization of hIgh Strength-high Performance Concrete. Paris: 1996. p. 571–7.
[6] Pyle RW. Product and method for incorporating synthetic polymer fibers into cement mixtures. U.S. Patent 6. 258, 10 July 2001. p. 159.
[7] Islam GS, Gupta SD. Evaluating plastic shrinkage and permeability of polyolefin fibber reinforced concrete. Int J Sustain Built Env. 2016;5:345–54.
[8] Alizade E, Jandaghi AF, Zabihi S. Effect of steel fiber corrosion on mechanical properties of steel fiber reinforced concrete. Asian J Civ Eng. 2016;17:147–58.
[9] Berrocal CG, Lundgren K, Löfgren I. Influence of steel fibers on corrosion of reinforcement in concrete in chloride environments: A review. Proceedings of the 7th International Conference Fibre Concrete. Prague, Czech Republic: 2013. p. 12–3.
[10] Anandan S, Manoharan SV, Sengottian T. Corrosion effects on the strength properties of steel fibre reinforced concrete containing slag and corrosion inhibitor. Int J Corros. 2014;2014:595040.
[11] Granju JL, Balouch SU. Corrosion of steel fiber reinforced concrete from the cracks. Cem Concr Res. 2005;35:572–7.
[12] Mihashi H, Ahmed SFU, Kobayakawa A. Corrosion of reinforcement steel in steel fiber reinforced concrete structures. J Adv Concr Tech. 2011;9:159–67.
[13] Bagherzadeh R, Pakravan HR, Sadeghi AH, Latifi M, Merati AA. An investigation on adding polypropylene fibers to reinforce lightweight cement composites. J Eng Fibers Fabr. 2012;7:13–9.
[14] Tagnit A, Vanhove Y, Petrov N. Microstructural analysis of the bond mechanism between polyolefin fibers and cement pastes. Cem Concr Res. 2005;35:364370.
[15] Neeley BD, O'Neil EF. Polyolefin fiber reinforced concrete. Proceedings of the Materials Engineering Conference: Materials for the New Millennium. 1, Washington, DC, USA: November 1996. p. 113–122.

[16] Lin W, Cheng A. Effect of polyolefin fibers and supplementary cementitious materials on corrosion behavior of cement-based composites. J Inorg Organomet Polym. 2013;23:888–96.

[17] Balaguru PN, Shah SP. Fiber reinforced cement composites. Singapore: McGrawHill. Inc, 1992.

[18] Furlan S, De Hanai J. Shear behavior of fiber reinforced concrete. Cem Compos. 1997;19(4):359–66.

[19] Meddah MS, Bencheikh M. Properties of concrete reinforced with different kinds of industrial waste fiber materials. Constr Build Mater 23(10):3196–205.

[20] Iraqi Standards No.5/1984. Ordinary Portland cement. Ministry of Housing and Construction, Baghdad; 2004.

[21] Iraqi Standards No.45/1984. Aggregate from Natural Sources for Concrete and Construction. Ministry of Housing and Construction, Baghdad; 2004.

[22] ASTM C 494-04. Standard specification for Chemical Admixtures for Concrete. ASTM International, American Society of Testing Materials, USA. 4.2, 2004.

[23] BS EN 12390-3, 2009, "Methods for Determination of Compressive Strength of Concrete Cubes," published by BSI.

[24] ASTM C78-02. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-point Loading). 4.2, 2002. p. 1–3.

[25] ASTM C496/C496M-04. Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. 4.2, 2004. p. 1–5.

[26] ASTM C 805-02. Standard Test Method for Rebound Number of Hardened Concrete. 4.2, USA: ASTM International, American Society of Testing Materials; 2002.

[27] ASTM C 597-02. Standard Test Method for Pulse Velocity through Concrete. 4.2, USA: ASTM International. American Society of Testing Materials; 2002.