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Destructive and Nondestructive Tests for Concrete Containing a Various Types of Fibers

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Abstract

Fibers have been considered an effective material that was used to improve the concrete's weak properties, namely its tensile strength, ductility, and crack resistance. Thus, the current study highlights two major objective, the former is the fibers shapes and types on the mechanical properties of the fresh and hardened concrete while the latter explores the impact of the fiber contents on the concrete mechanical properties developments. To achieve these targets six types of fibers (five of them made of steel and the last was polyolefin fibers) with various shapes are utilized. The tests were carried out to investigate the fibers shape and material contribution in the concrete mix properties improvement. The samples were subjected to destructive and non-destructive tests such as workability, compression, bending, and splitting. The non-destructive tests include ultrasonic pulse velocities and the Schmidt Hammer test. Three kinds of fibers (two of steel and one of polyolefin fiber) are used with variable content ratios of 0.5, 0.75, 1.0, and 1.5% to study the fiber content effect. Generally, the workability of fresh concrete has a reverse relationship with fiber presence and fiber content ratios. The compressive capacity, splitting and flexural strength has a direct proportion with fibers contents. The hooked steel fibers appeared the best results in terms of shape comparison.

Keywords: Fibers; Compressive Test; Tensile Strength; Concrete Additive.

1. Introduction

Today, concrete and its production represent the cornerstone of construction and infrastructure work. However, it is still considered a brittle material. There are many research studies that propose variable solutions to tackle this problem. Different types of fibers, such as steel, carbon, alcohol polyvinyl, glass, and metal fibers, are suggested as additive materials to increase the ductility of concrete and reduce cracking, for example, polypropylene and acrylic [1]. Due to its low cost, fresh and hardened concrete properties like compression, tension, and workability were developed by adding polyolefin and polypropylene as well as plastic fibers [2-4]. The shape, such as embossed, straight, and crimped, and the material of the fibers, like waste polyethylene and steel, were conducted to have a crucial effect on the concrete characteristics [5, 6]. The recycled steel fibers were substantially used to develop the shear and flexural properties for both normal and self-compacting concrete (SCC), the steel fibers have waved shapes and contents, and the concrete beams casted with steel fibers were explored [7-9].

The concrete beams flexural characteristics with steel fibers had explored intensively to obtain the fibers impact on the beams bending strength [10-12]. To provide the best and main benefits of the structural strength the polyolefin fibers are used for such purposes. Based on the major advantages such as increasing structural strength, polyolefin fibers are commonly used [13, 14]. An analytical and experimental study that deals with reinforced concrete beams under bending with steel fibers to predict the fibers' impact on the flexural behavior of those beams [15].

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Influence of fiber length on the performance of polypropylene (PP) fiber reinforced cement concrete were studied by Lashari et al. [16], they observed that the compressive strength and flexural strength of concrete were significantly affected by the length of the PP fibers. When a higher fiber volume is used, short PP fibers exhibit better compressive strength but lower flexural strength, whereas longer PP fibers exhibit lower compressive strength but higher flexural strength. Also, the optimum dosage for both sizes of PP fiber was 0.25%, which achieved enhanced strength compared to the control sample.

Jassam et al. [17] examined experimentally the effect of adding different types of fibers on the engineering properties of high-strength concrete. The samples are divided into three groups, the first set only contains polypropylene fibers, the second group including 0.5% steel fibers with different amounts of polypropylene fibers 0 to 0.5%. The last group consists of 1.0% steel fibers with variable quantities of polypropylene fibers ranging from 0 to 0.5%. They found it when Compared to the mixture of ordinary concrete, the mixture that contains fibers shows a major improvement in compressive and flexural strength. The maximum compressive strength and flexural tensile strength have been recorded for concrete strengthened with a combination of 1% steel and 0.2% polypropylene fibers.

Several studies have been conducted on each kind of fiber in terms of the effects of the sizes, aspect ratios, and contents of fibers relative to the volume of concrete on the characteristics of hardened concrete. Thus, the main target of this research is to discover the influence of adding a different type of fiber inside concrete in order to improve the concrete's mechanical properties, which were tested by destructive and non-destructive methods. On the other side, non-destructive examinations were conducted to produce a better understanding of the additive fiber effectiveness on the characteristics of the concrete and then assist in the evaluation of existing fiber reinforced concrete constructions.

2. Experimental Work Program

In this investigation, an experimental procedure which includes many tests for either fresh or hardened concrete were done for both a plane as well as fiber reinforced concrete. In order to examine the concrete workability, a slump test was applied for all mixes. In term of hardened concrete properties investigation, the studied properties were compressive, splitting and flexural strengths of 150×150×150 mm cubes, 300×150 mm cylinders and prism of 100×100×350 mm were cast and evaluated, respectively. The research plan included adding six types of fiber (hooked steel fiber 60 mm, hooked steel fiber 50 mm, hooked steel fiber 30 mm, twisted steel fiber 30 mm, straight steel-fiber 12 mm, Polyolefin fiber 60 mm) having different size, shapes and materials with two parts. The former part is conducted by adding fiber with a constant ratio (1% of the total concrete mix volume). While the later part is achieved by adding three chosen types of fibers (polyolefin fiber 60 mm, straight steel-fiber 12 mm, hooked steel fiber 6 cm) with five different ratios 0.0, 0.5, 0.75, 1.0, and 1.5% of the whole mix concrete quantity. The six fibers types which used in this study are listed below, whereas the work plan of this study is summarized in the flow chart described in Figure 1.

- *6 cm steel fiber, hooked type*
- *3 cm hooked end steel fiber*
- *1.2 cm of straight steel fiber*
- *5 cm hooked steel fiber*
- *3 cm of twisted steel fiber*
- *6 cm Polyolefin fiber type*

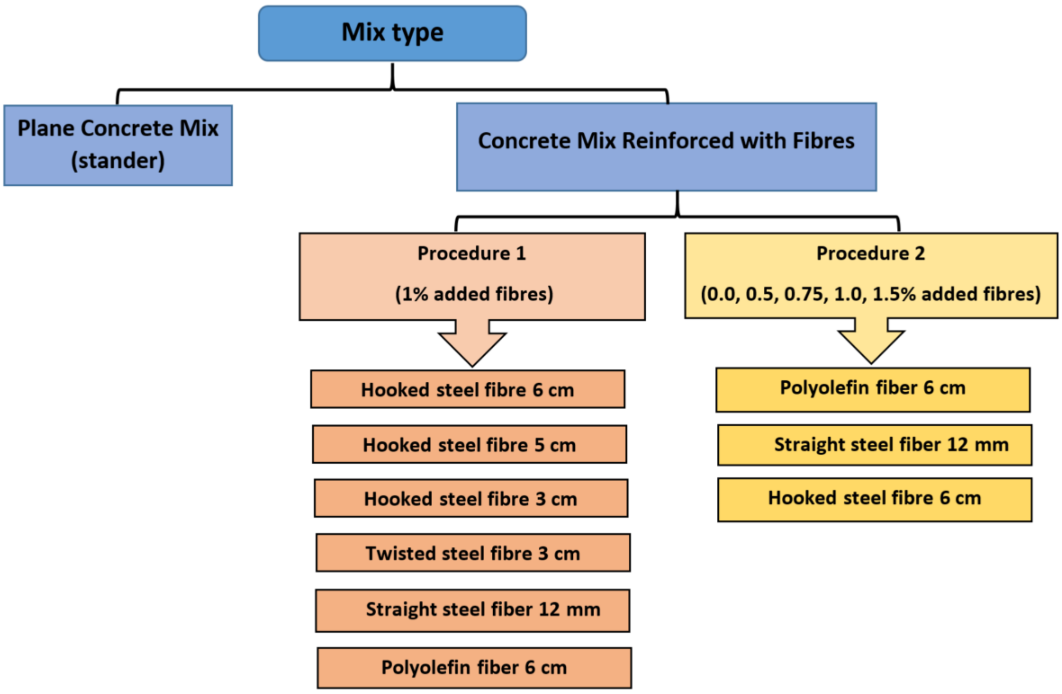

Figure 1. Research plan

2.1. Materials

The utilized materials in this investigation mainly depending on the location, convenience and availability of materials. In this section a brief description of those material which was subjected to different tests according to the ASTM standard in order to test its properties and suitability to this study demands.

Cement

Ordinary Portland cement conforms to ASTM C150-15 [18] specification requirements was used in this study. The chemical composition and physical test results of the cement used are listed in Table 1.

Table 1. Physical and chemical test results of the used cement

Physical test results			
Test	Unit	Result Test	ASTM C 150 [18] Limits O.P.C- Type I
Initial Setting Time	Minute	133	45 - 375
Compressive strength			
3 days age	MPa	16.4	12 min.
7 days age	MPa	27.2	19 min.

Chemical test results			
Test		**Result Test**	**ASTM C 150-15 [18] 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	6.0 max.
	C_3A	3.3	---
	SO_3	2.25	3.0 max.
L.O.I %		2.75	3.0 max.
I.R %		0.52	0.75 max.

Fine Aggregate

Natural sand was used in the city of Basrah in the Sanam mountain zone. Table 2 and Figure 2 display fine aggregate grading and ASTM C33-15 limits [19], Table 3 expresses the physical and chemical test results of the used fine aggregate

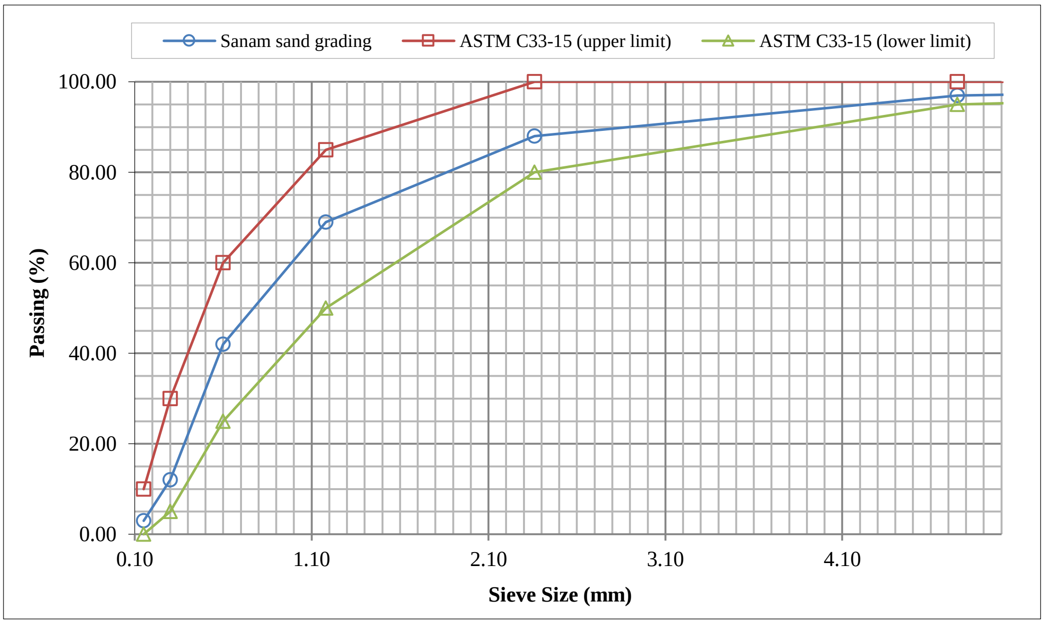

Figure 2. Sieve analysis of adopted sand

Table 2. Grading of sand

Sieve size (mm)	Percent Passing	
	Fine aggregate	Limits of ASTM C33-15 [19]
9.5	100	100
4.75	97	95- 100
2.36	88	80- 100
1.18	69	50- 85
0.6	42	25- 60
0.3	12	5- 30
0.15	3	0- 10
0.075	1.5	0-3

Table 3. Sand properties

Test	Result
Fineness Modulus	2.91
Specific gravity	2.65
Sulfate content (SO_3) percent	0.33
Absorption percent	1.20
Bulk density (loose) kg/m^3	1645

Coarse Aggregate

A crushed gravel with size (19-4.75) mm was used from the area of the Sanam Mountain in Basrah town. Table 4 and Figure 3 show coarse aggregate grading complies with ASTM C33-15 [19]. The Specific gravity, content of sulfate, chloride and the coarse aggregate absorption are described in Table 5.

Table 4. Grading of the gravel used

Sieve size (mm)	Percent Passing	
	Coarse aggregate used	Limits of ASTM C33-15 [19]
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

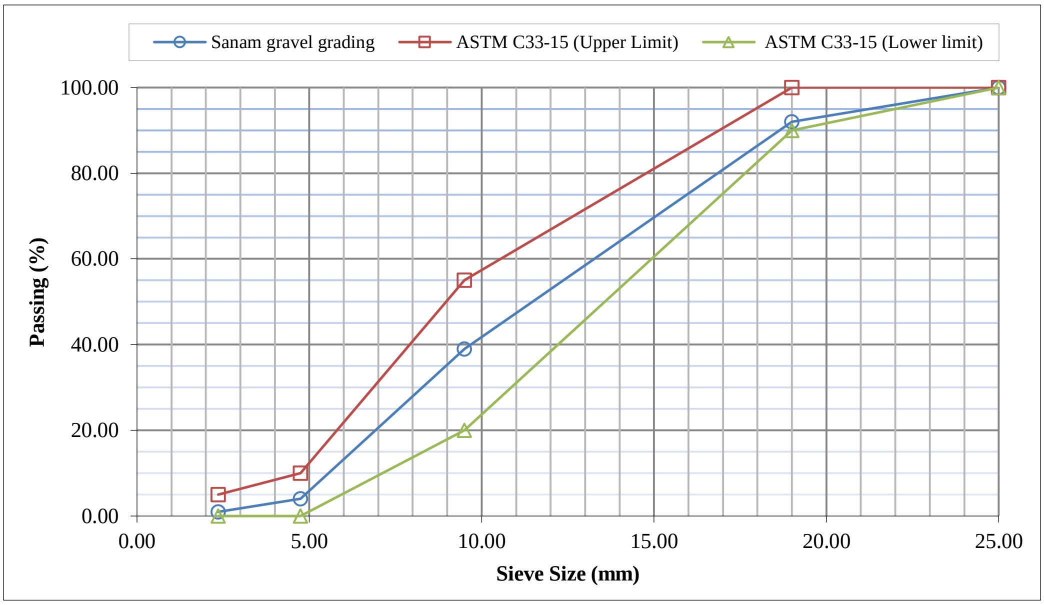

Figure 3. Sieve analysis of adopted gravel

Table 5. Physical and chemical test results of the gravel used

Test	Result
Specific gravity	2.61
Content of sulfate (SO3)	0.083 %
Content of chloride (Cl)	0.097 %
Absorption	0.85 %
Bulk density (loose) kg/m^3	1588

Fibers

As mention above six types of fibers are used in this research namely: Hooked steel fiber 6 cm, 5 cm, and 3 cm, twisted steel type fiber 3 cm, straight steel fiber 12 mm and Polyolefin fibers 6 cm. Figure 4 shows these fibers. Normal steel fibers used in the first fifth types while the last one was a Polyolefin fiber which consist mostly of macromolecules, saturated aliphatic.

Hooked steel fiber 60 mm

Hooked steel fiber 50 mm

Hooked steel fiber 30 mm

twisted steel fiber 30 mm

straight steel fiber 12 mm

Polyolefin fiber 60 mm

Figure 4. The fibers types used in the study

A polyolefin is classified as a produced fiber in which any synthetic long-chain polymer composed by a mass of ethane, propene, or other olefin units at least 85 percent is formed by the fiber former. In this study SikaFiber® Force-60 was depended. Table 6 illustrates the SikaFiber® Force-60 technical information.

Table 6. Technical data for all used fibers

Type	Shape	Length (mm)	Diameter (mm)	Aspect ratio	Tensile strength (MPa)
Steel fiber (hooked)	Hooked ends and straight middle	60	0.75	80	>1000
Steel fiber (hooked)		50	0.9	55	>1000
Steel fiber (hooked)		30	0.5	60	>1000
Steel fiber (crimped)	Twisted	30	0.55*	55	>700
Steel fiber (straight)	Straight	12	0.25	50	2850
Fiber of polyolefin	Straight, embossed, white	60	0.84*	71	465

* Equivalent fiber diameter

Water

Ordinary drinking water was used for mixing and curing of concrete.

Superplasticizer

Super plasticizer (HWRA) based on polycarboxylic ether is depended to produce high-performance concrete. Sika F-180g is utilized in this work which satisfy the requirements of the ASTM C494-04 [20], Type A, and Type F are compliant.

2.2. Mix Proportions

In this study only one mix proportion was used with different polyolefin fibre shape and content as summarised before in order to clarify the effect of these variables (fibres shapes and content) on the concrete workability, the specimen molds shown in Figure 5, mix proportion was exhibited in Tables 7 and 8.

Figure 5. Test specimen molds

Table 7. Mix proportion

Mix	Cement	Fine Aggregate	Coarse Aggregate	Water /cement	Superplasticizer /cement
Ratio	1.0	1.5	2.5	0.4	0.5%

Table 8. Mix symbols with used fibers

Mix NOTATION	Fiber Type and shape
CF0	No fiber
CF1	6 cm hooked steel-fiber
CF2	5 cm hooked steel-fiber
CF3	3 cm hooked steel-fiber
CF4	3 cm twisted steel-fiber
CF5	1.2 cm straight steel-fiber
CF6	6 cm Polyolefin fiber

The first group procedure investigates the effect of the fiber shapes on the mix properties as well as the hardened concrete, consequently the fiber content in all mixes remains constant and equal to 1 % of the total mix volume. Furthermore, second group is adopted to study the effect of fiber volume, so that three types (hooked steel-fiber 60mm, straight steel-fiber 12 mm and Polyolefin fiber 60 mm) were selected with variable fiber contents (0.00, 0.50, 0.75, 1.00 and 1.50 percent of the total mix volume).

3. Test Methodology

In terms of hardened concrete properties evaluations, a compressive strength of fiber reinforced concrete was tested in accordance with BS EN 12390-3:2009 [21]. Six cubic specimens with dimensions 150×150×150 mm were moulded casting and tested after 7 and 28 days of storage in fresh water for each mix. Then they were tested by utilizing a machine which had a capacity of 2000 kN to determine the compressive capacity for those samples. The splitting tensile strength was determined by the cylindrical specimens (150×300 mm) according to standard ASTM C496/C496M-04 method [22]. Moreover, prisms (100×100×350 mm) are tested for flexure with respect to ASTM Standard C78/C78M-02 method [23]. Both cylinders and prisms were tested after 28-days of curing in water. The workability of the fresh concrete had been assessed by slump test as shown in Figure 6.

Figure 6. Workability examinations using slump test

On the other side, non-destructive tests were conducted to have a better understanding of the additive fibres effectiveness on the properties and characteristics of the concrete. As a response, the 150 mm cube specimens' rebound number was determined using a Schmidt hammer in accordance with ASTM C 805-02 [24]. As shown in Figure 7, the concrete cubes' ultrasonic pulse velocities (UPV) were measured in accordance with ASTM C597-02 [25] using transducers with a frequency of 54 kHz.

Schmidt Hammer Test UPV Test

Figure 7. Nondestructive tests

4. Results and Discussion

4.1. Group 1

Fresh Concrete Test

In this section details of the results of fresh and hardened concrete for the investigated mixes were presented. As mentioned before, for group one both fiber contents (1%) as well as mix proportion remained constant in the same time variable six types of fibers had been added. Consequently, the reflected effect of the fibers shape and type was explored. Table 9 describes the results of the fresh concrete workability test. In addition, Figure 8 shows these results graphically.

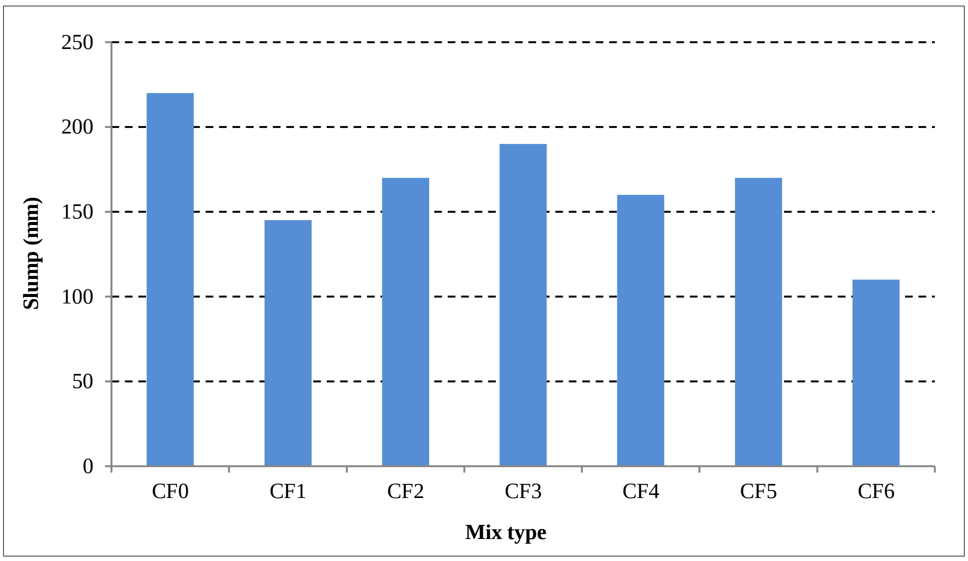

Figure 8. Slump values for group one mixes

Table 9. Slump test results

		Mix Type	Slump (mm)
Fiber contents (1 %) of the total concrete mix volume	CF0	Without fiber	220
	CF1	Hooked steel fiber 6 cm	145
	CF2	Hooked steel fiber 5 cm	170
	CF3	Hooked steel fiber 3 cm	190
	CF4	Twisted steel fiber 3 cm	160
	CF5	Straight steel fiber 1.2 cm	170
	CF6	Polyolefin fiber 6 cm	110

In general, all the fiber types caused a remarkable decrease in the slump results and the interpretation for that is the fact that the interlock between the fibers and the other mix contents characterization which leads to slump dropping. The data recorded from the slump tests showed that the mix workability with hook steel fibers was decreased gradually with fiber length increasing. Moreover, it can be seen that the mix with fiber having the same length fiber (3 cm), the twisted fibers exhibited slump lower than the hooked end shape fibers. Form Table 9 it can be seen that the straight steel fibers 1.2 cm showed slump higher than that of hooked fibers 3 cm this is interrupted to the smaller length leads to high distributed density in the mix which follows workability decreasing.

Compressive Strength (Destructive Test Results)

The cubes for all the mixes (with fiber content 1%) have been tested in two different ages; 7 and 28 days respectively. The results of the destructive compressive test for those samples are expressed in Table 10.

Table 10. Compressive strength for group 1

Mix Type	Compressive strength (MPa) 7 days	Compressive strength (MPa) 28 days
CF0	41.76	44.30
CF1	48.37	53.90
CF2	47.67	49.40
CF3	48.66	50.71
CF4	60.42	62.12
CF5	52.00	55.08
CF6	42.10	48.31

From the Table 10 it can be observed that the compressive strength generally increased when the fibers were added to the mixes, Figure 9 expresses that best improvement in the compressive capacity occur when in mix CF4 (which contains the twisted fibers) by gain 49.3 % compared with mix CF0, while the lower development was recorded by CF6 (polyolefin fiber 6 cm) by 9.03 % only at age 28 days.

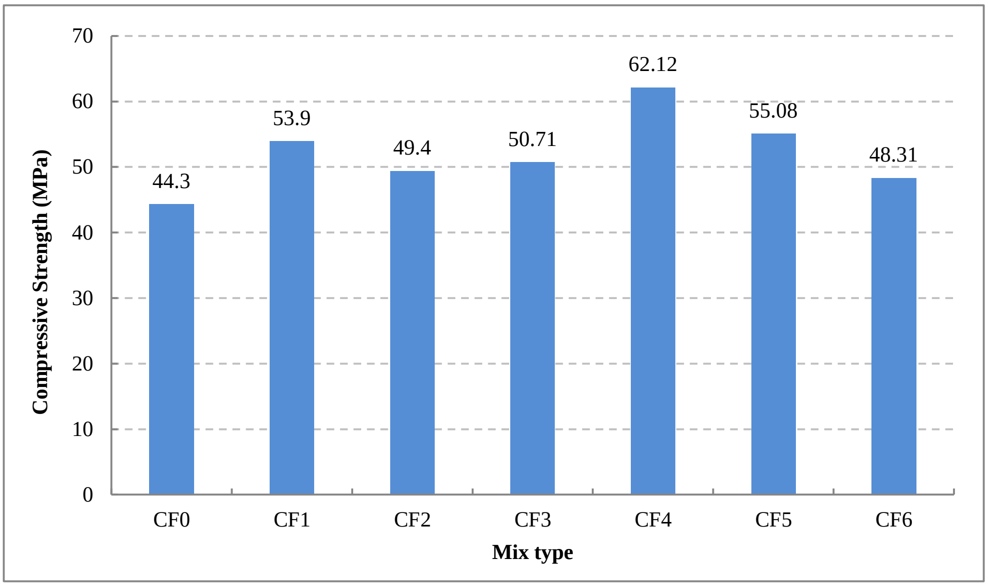

Figure 9. Compressive strength results (destructive test)

The other four fiber additive mixes showed a similar trend of compressive strength with gradual rising. This development in the concrete cube compression can be interpreted due to a genuine effect of the fibers which increase the concrete ductility and micro-crack resistance, consequently the fracture energy of the concrete raised and this leads to the crack propagation delayed in presence of fibers. In addition, the fibers increase the internal bond of micro concrete structure among the mix contents especially for the twisted fibers which provides a better bond. This fact clearly appeared in the results. The compressive strength of cubes with 7 days' age states same trends as was described in Table 10.

In addition, the compressive strengths also investigated by a non-destructive test. Table 11 illustrates the predicted compressive strength extracted from the rebound numbers (RN) came from Schmidt hammer test. Figure 10 describes the relationship between actual cubes strength and the predicted compressive stress calculated by Equation 1 below:

$$f_{cu} = 0.0482\,RN^2 - 3.7162\,RN + 120.63 \quad (1)$$

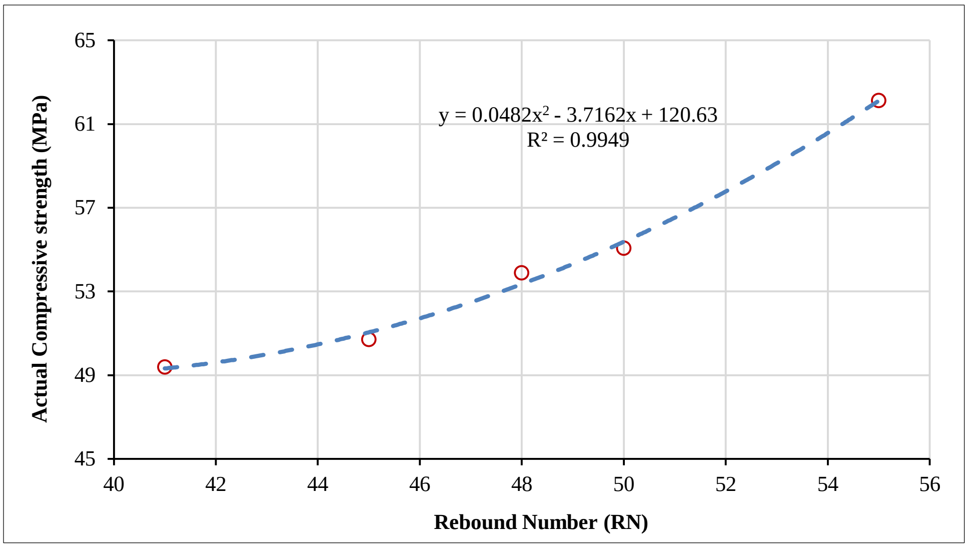

Figure 10. Rebound number vs. Actual compressive strength relation

The results show that there is good agreement between the two values (actual and predicted). The presence of steel fibers leads to improve the concrete strength capacity. The result comes from CF6 (the mix with polyolefin fiber) not included in this comparison due to the material differences. Also, the ultra-sonic pulse velocities test was applied and Figure 11 illustrates the compressive strength predicted using Equation 2 which was concluded from that test. It is observable that the predicted compressive stress using Equation 2 produce acceptable values when it compared with the actual values from destructive test of cubes. And as mentioned before the absence of the steel fiber reduced the wave velocity. Conversely, the mix with fibers have a higher UPV values recorded in Table 11.

$$f_{cu} = 0.0518\,V - 210.62 \quad (2)$$

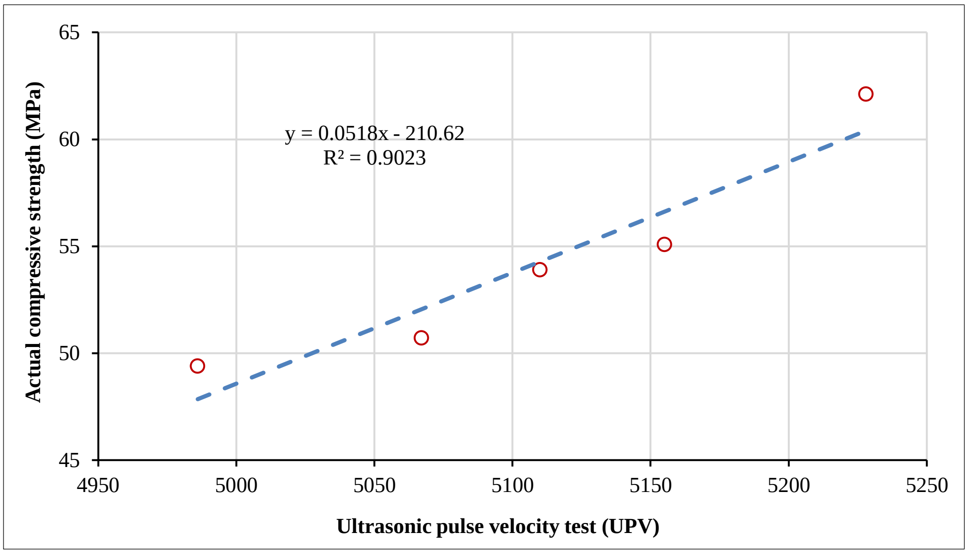

Figure 11. UPV vs Actual compressive strength relation

Table 11. Non-destructive test results for group 1

Mix Type	Schmidt hammer Rebound Number (RN)	Predicted Comp. strength from RN (MPa)	Ultrasonic pulse velocity test (UPV) (m/sec)	Predicted Comp. strength from UPV (MPa)	Actual Comp. strength (MPa) 28 days
CF1	48.0	52.71	5110	54.08	53.90
CF2	41.0	50.34	4986	47.65	49.40
CF3	55.0	50.43	5067	51.85	50.71
CF4	50.0	62.11	5228	60.19	64.12
CF5	45.0	55.65	5155	56.41	55.08

Splitting and Flexural Capacity

To assess the impact of the fiber's addition to the concrete mix contents it is necessary to investigate the effect of those fibers on the tension resistance of the concrete. Thus, in this section, a discussion of the casted samples prepared for this purpose will be dis played. First a concrete cylinder was tested on three samples with 28 days for each mix. The full results of these cylinders are described in Table 12 and Figure 12. Obviously, there were a significant jump in the splitting resistance when the fibers presence compared with the standard concrete mix consisted of plane concrete. Maximum resistance was almost doubled in case of CF1 mix while it increases by 92.3 % for CF2 compared with CF0. The other considerable development in the tension strength was recorded in all remaining mix as (72.2%, 42.9%, 77.7% and 44.9% for CF3, CF4, CF5 and CF6 respectively).

Table 12. Tension examination results for group 1

Mix type	Splitting strength (MPa) for cylinders	Flexural strength (MPa) for prism
CF0	2.87	4.41
CF1	6.63	10.42
CF2	5.52	9.42
CF3	5.00	8.72
CF4	4.10	7.85
CF5	5.10	6.84
CF6	4.16	7.36

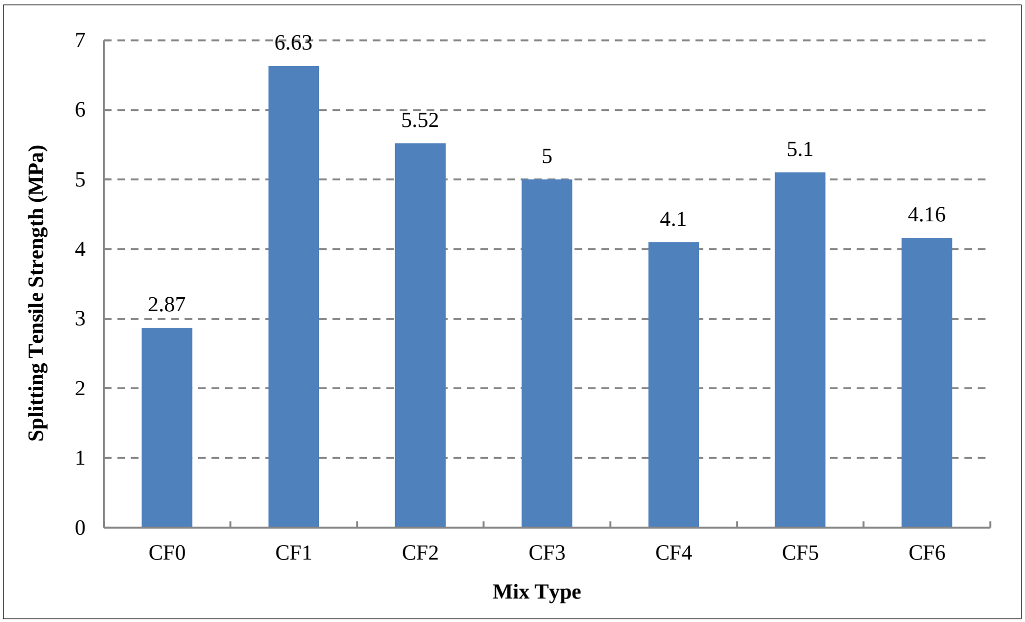

Figure 12. Splitting strength comparison

The concrete prisms at age 28 days also were examined in order to obtain a better understanding of the fibers effect on the concrete tensile resistance. Table 12 and Figure 13 displayed the results of those prisms. The bending resist that extracted from the tested prism showed a similar behavior of the indirect shear force calculated from the splitting of the cylinder before. The highest value 10.42 MPa was come from the CF1 mix by a considerable increase the plane concrete CF0 which was 4.41. in the same way the CF2 beams has approximately doubled tension strength values compared to the standard one (CF0). The explanation of these values is that the fact that the hooked steel fibers 6 cm and 5 cm have a better interlock and high strength force which will reflect on the mix properties after those fibers added to the mixes.

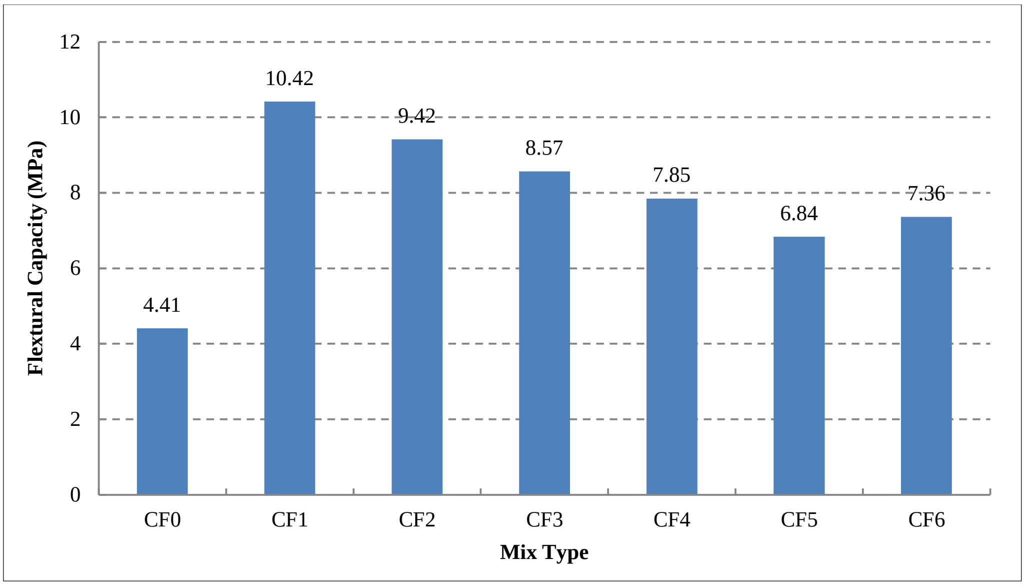

Figure 13. Flexural strength results

4.2. Group 2

Fresh Concrete Test

The main target of this section is to explore the effect of fibers content change in the mechanical properties of the concrete mix. Thus, three fiber types of the former group had been chosen to investigate its consequence on these mixes. Table 13 clarifies mix workability for each mixture form slump test.

Table 13. Slump (mm) test results group 2

Fiber Content ratio	Polyolefin fiber 6 cm	Straight steel fiber 12 mm	Hooked steel fiber 6 cm
0.00	220	220	220
0.50	200	190	200
0.75	170	180	150
1.00	140	170	100
1.50	100	130	20

Generally, the concluded results clearly show that the concrete with fibers, in comparison to plane concrete mix, has lower slump rate. The values decrease as the fiber content increase as shown in Figure 14. The presence of fibers can be the cause of this behaviour.

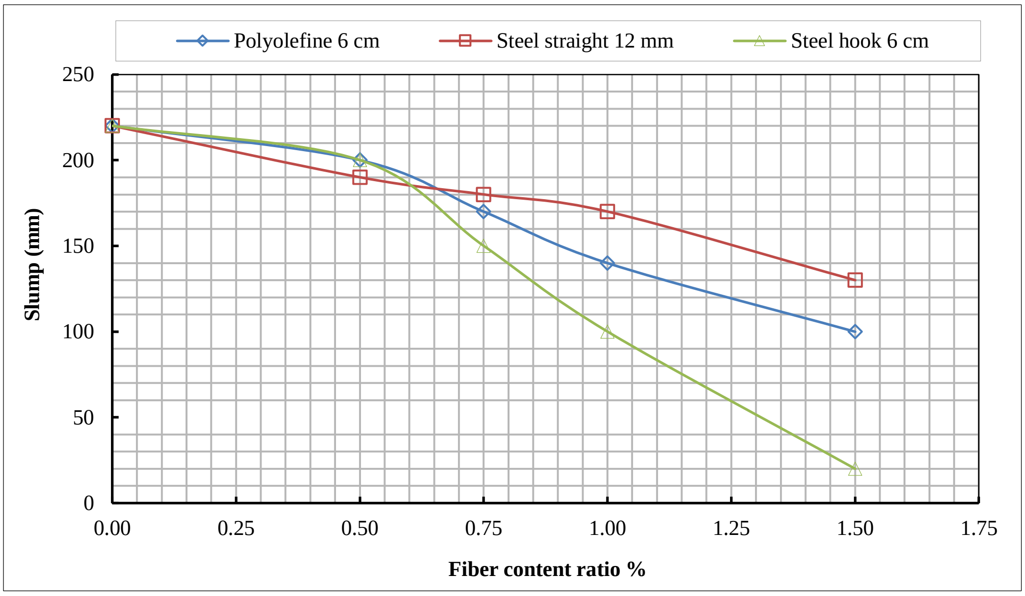

Figure 14. Workability test for group 2

Compressive Strength

The investigation results that focus on the impact of the fibers content ratio illustrate in this section. Figure 15 display the relationship between the compressive stress values for the cubes (28 days) and the three chosen fibers. For the steel fiber effect, it can be observed that the strength of the concrete has direct proportion with fibers content ratios. The mix with polyolefin fibers shows a similar behavior till 1% ratio then the compression of the cubes dropping, this behavior could be explained due to the fact that high density of this types of fiber will reduce cube resistance. This is because of the fact that polyolefin fibers have lower strength as mentioned in Table 6 before.

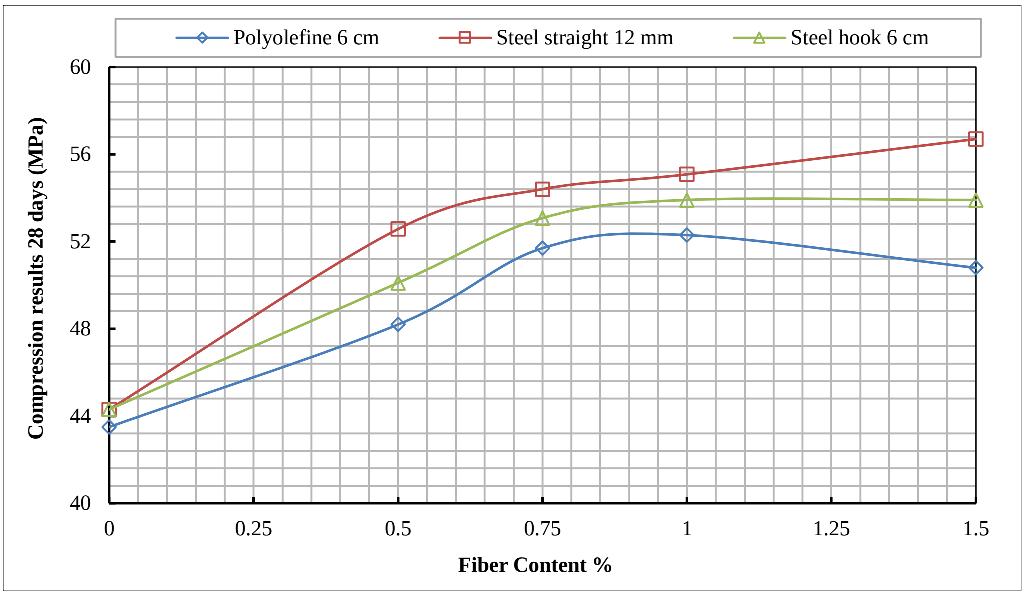

Figure 15. Compressive strength for group 2

Splitting and Flexural Resistance

The strength of the cylindrical concrete specimens was measured to explore the fiber content's effectiveness on the indirect shear resistance of fiber-reinforced concrete. Figure 16 describes the values of the concrete splitting capacity versus the fiber content. It is clear that the best values of the tensile stress were recorded when the hooked steel fiber was used. Moreover, in terms of the steel fibers, the ductility of the concrete increased as the fiber content increased, and the hooked fiber has higher values than the straight one due to the better bond and interlock provided by the first one (hooked).

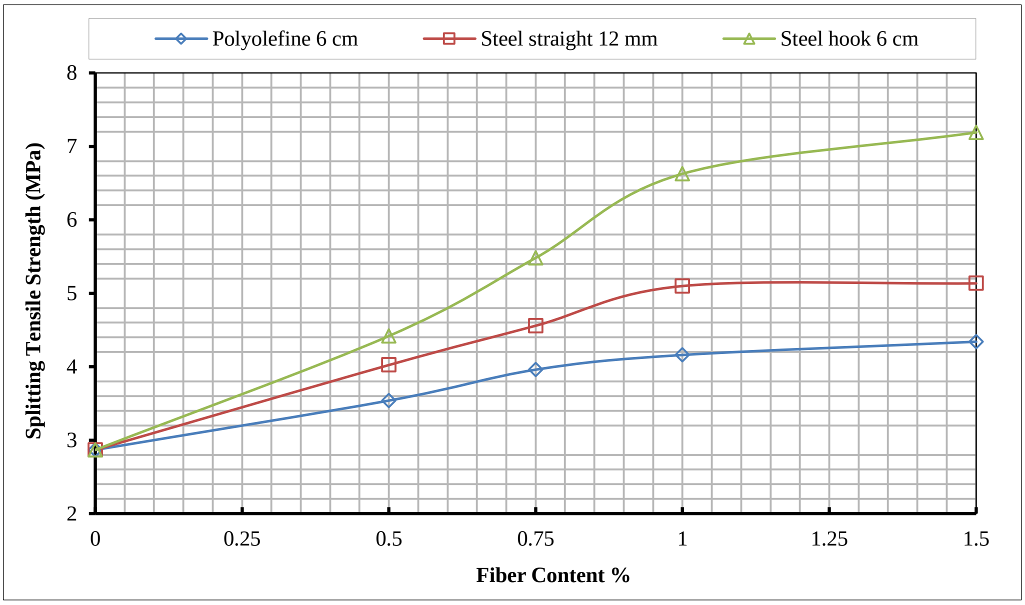

Figure 16. Splitting results (28 days) for group 2

The polyolefin fibers show a similar behavior to the steel fiber effect; however, they had a lower value compared with steel fibers for all the content ratios due to the fact that the latter has a higher strength, as mentioned in Table 6 before.

The test prism results, which investigate the flexural resistance of the concrete reinforced by fibers, are illustrated in Figure 17. Obviously, the results of the splitting test show similar behavior. The concrete bending stress showed a direct proportion for all fiber types. The additive fibers caused a considerable increase in the flexural resistance. This strength improved significantly in case of hooked steel fibers. The mix with straight fibers showed same development as fiber content rising. The interpretation of this behavior is that the presence of fibers enhanced the concrete's tensile strength and led to an increase in its fracture strength. The polyolefin fibers in the concrete showed almost similar trends. However, it recorded lower values as compared with the steel fiber mix. This fact can be concluded easily due to the lower tensile strength of the polyolefin fibers when compared with steel fibers (revise Table 6). This can be attributed to the fiber type; its length, volume fraction, and bond with the concrete matrix have a significant influence on the response of the composite. The short fibers bridge tensile microcracks, and the long fibers are on the macrocrack stage [26].

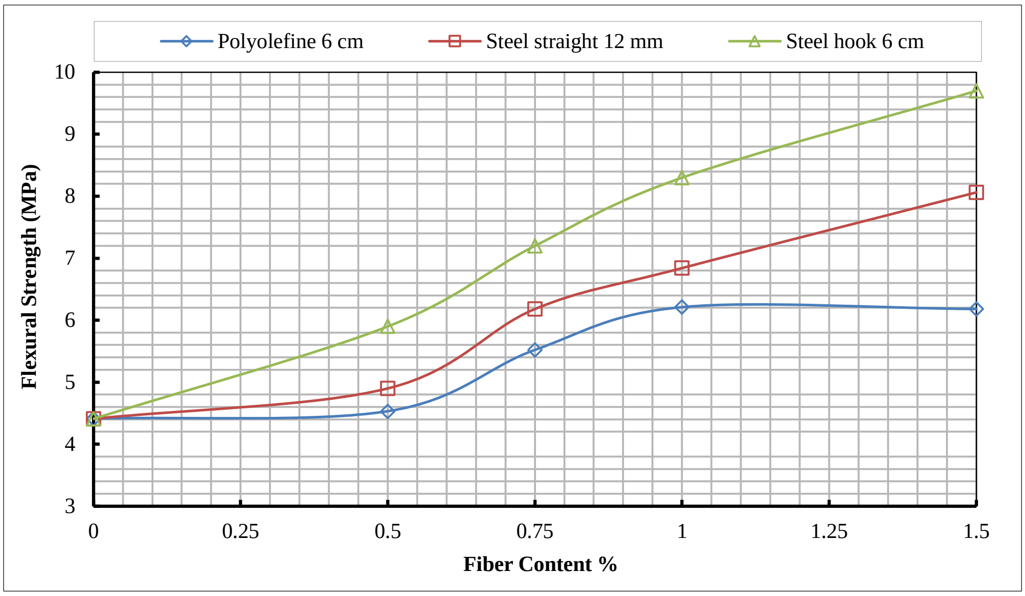

Figure 17. Flexural strength results (28 days) for group 2

5. Conclusions

This study has two main objectives namely: investigate the fiber type and shape on the plane concrete mechanical properties (compressive, splitting and flexural), explore the fibers content effect on the concrete strengthened improvement. Thus, the samples were divided into two major groups to achieve the study targets. Group one samples generally showed that the compressive strength developed substantially in the presence of all steel fiber types. However, the hooked steel fibers 6 cm and twisted fibers stated the best compressive capacity compared with other steel fibers shape. On the other hand, the polyolefin fibers appeared in smaller increments than the steel fibers. In terms of non-destructive tests, two devices have been utilized to conduct a predicted compressive stress from rebound number (Schmidt Hammer) and the Ultrasonic Pulse Velocity (UPV) test. Two equations were suggested to calculate the predicted strength and compare it with the actual compressive strength. Those results showed good agreement with the values that came from destructive compressive tests. Splitting and flexural strength both decreased significantly in the absence of fibers. The best tension strength was recorded in the case of hooked fibers (6 cm), in which the tensile stress was almost doubled when compared with the concrete without fibers. The steel fibers have a better effect than the polyolefin fibers due to their properties.

Group two focused on fibers content effectiveness on plane concrete characteristics, consequently, the fibers contents are changed 0.0, 0.5, 0.75, 1.0, and 1.5% from the total mixes volume. The concluded results showed that the compressive strength increased considerably with fibers contents increase. Except for polyolefin fiber concrete, the maximum content is 1% to get best strength after that diminish progressively of compressive strength was observed. In addition, the tension resistance (splitting and flexural) improved significantly as the fiber contents increased. The workability of the mixes has a reverse relationship with the fiber contents. Moreover, generally, the absence of fiber leads to slumping values. There was a direct proportion between the concrete ductility (mix content bond and interlock, crack initiation and propagation) with presence of fibers.

In order to have a clear understanding of the effect of fibers on the properties of fiber-concrete, it is highly recommended to study the microstructural and macrostructural properties of fiber-concrete by using special instruments like an environmental scanning electron microscope. Furthermore, comprehensive research on the long-term durability of concrete made with fibers is strongly suggested.

6. Declarations

6.1. Author Contributions

Conceptualization, I.S.; methodology, M.M.; formal analysis, S.F.; investigation, I.S.; resources, S.F.; data collection, S.F.; writing—original draft preparation, I.S., S.F., and M.M.; writing—review and editing, M.M. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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6.5. Conflicts of Interest

The authors declare no conflict of interest.

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