Journal of Engineering Science and Technology
Vol. 16, No. 2 (2021) 1746 - 1760

BEHAVIOR AND STRENGTH OF POLYPROPYLENE REINFORCED CONCRETE SLABS

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Abstract

The purpose of the present work is to study experimentally polypropylene fiber effect on the concrete mechanical properties as a material and Behavior and the strength of polypropylene fiber reinforced concrete slab specimens. Nine reinforced concrete slabs with dimensions of 600mm × 700mm × 120 mm were cast and tested to check out the effects of polypropylene fiber in improving their structural Behavior. Three different values of concrete compressive strengths are adopted (30, 40 and 60 MPa) with three different percentages of polypropylene fiber (0% for control specimens, 0.4 and 1.0 % by cement content) for each value of compressive strength. All specimens were tested under static concentrated loading at the center of slab and the four edges of all the specimens are assumed to be simply supported. Prior crack, post crack, ultimate capacities and modes of failure are investigated. The experimental results showed a noticeable increase in concrete strength by using polypropylene fiber which also works as crack bridging. The amount of increase in compressive strength for fibrous concrete as compared with non-fibrous concrete for group A (which is of 30 MPa) is 28% and 36 % for 0.4% and 1.0% fiber content, respectively. While, for group B (which is of 40 MPa), the percentage of increase was about 26.8% and 35.3% for 0.4% and 1.0% fiber content, respectively. In group C (which is of 60 MPa), the percentage of increasing of the compressive strength was about 27.3 and 31.3 % respectively. Also, the concrete compressive strength could be increased, and the cracks width could be decreased by adding polypropylene fibers to the mixes. The experimental investigation indicated that the percentages of increase in ultimate load values for all the three groups are 14.1% (for slab No. 3 (S3)), 14.93% (for slab No. 6 (S6)), and 17.86% (for slab No. 9 (S9)) respectively compared to their control sample for 1.0% of polypropylene fiber. Limited cracks propagation was noticed with the increased fiber percentage so that improved concrete Behavior was obtained.

Keywords: Concrete compressive strength, Crack width, Mechanical properties, Polypropylene fiber, Reinforced concrete slabs.

1. Introduction

In spite of the fact that concrete is widely used in many structural members, it is still suffered from many shortcomings that restrict its application such as poor toughness, little tensile and flexural strength, and high brittleness. In order to enhance concrete properties, improving its mechanical performance and increasing its load capacity, some additives have been used in recent years like horsehair, plastic raw materials, steel, glass and numerous fiber types (polypropylene, carbon etc). Fiber reinforced concrete has been effectively utilized in structural constructions for its great flexural rigidity, supportability, and sustainability. The polypropylene fibers are characterized by low elastic modulus, best quality, ductility and durability, low cost, minimal effort, and effectively physical and chemical reformation. The material properties of polypropylene fiber are somewhat variable that rely on the fiber concentration and the form of the fiber. It was not until the 1960s that researches related to fiber reinforced concrete were carried out and developed [1].

Concrete beams reinforced with Polypropylene fiber were tested by Wu [2]. Deformation characteristics and strength of these beams with fiber contents such as (0.2, 0.5, l.0 and 1.5%) by volume were studied. Test results indicated that the strength and flexural toughness of these beams were altogether expanded, and the flexural sturdiness enhanced when contrasted with that of unreinforced concrete beams. Sukontasukkul [3] adopted the two different approaches (i.e., ASTMC1018 and JSCE-SF4) in order to measure the strength of the reinforcement as well as polypropylene fiber reinforced concrete beams exposed to bending. The results demonstrated that in the (JSCE) technique, the data obtained by only one specified deflection hardiness appeared to be deficient in reflecting the Behavior and characteristics of the load-deflection relation for both fiber reinforced concrete beams. While in ASTMC1018 technique, the obtained information utilizing the toughness, four values at various deflections appeared to be more readily clear in explanation the uniqueness of both fiber reinforced concrete beams.

Mahoutian et al. [4] researched steel fibers and polypropylene fibers effect on splitting tensile strength values, compressive strength and stress-strain relationship in which polypropylene or steel fibers were utilized to upgrade concrete ductility. Test results showed that high compressive and tensile strengths could be gained by using polypropylene fibers reinforced.

Abbas [5] studied the effects of polypropylene fiber on flat plate roofs subjected to elevated temperatures. One group of slab specimens was tested in room temperatures and three groups' specimens were tested with different degree of elevated temperatures. It was concluded that the existence of polypropylene fiber improved the strength capacity of the slabs under temperature load.

Mtasher et al. [6] investigated polypropylene fiber effects on the compressive and flexural strengths of ordinary concrete. Only four various concrete mixes of polypropylene fiber in with (0.4, 0.8, 1.0 and 1.5%) of cement content were utilized. Test results indicated that the concrete mechanical properties were improved especially concrete tensile strength because of polypropylene fiber presence.

Topçu and Baylavli [7] investigated the effect of polypropylene fibers with various characteristics on the flexural strength and deflection value of concrete beams with dimensions of (150x150x550 mm). The obtained results showed that flexural strength increased in contrast with the deflection by polypropylene fibers presence.

Alsadey and Salem [8] investigated the effect of polypropylene fiber on concrete compressive strength. They noticed by their research that the increase in polypropylene fiber content leads to an increase in compressive strength. Al-Shatheret et al. [9] concluded that the ultimate strength of concrete contained polypropylene fiber will increase and the cracks will decrease furthermore, the concrete compressive strength increased with improving in the tensile values.

Sohaib et al. [10] presented an experimental work to achieve the maximum strength of concrete by using the optimum weight of polypropylene fibers. 40 cylinders of polypropylene concrete were casted and tested for 7 and 28 days strengths for both compressive and split tensile strengths. It was concluded that the significant improvement was observed in ultimate compressive strength after 7 and 28 days. The optimum percentage of Polypropylene fiber was obtained to be 1.5 percent of cement by volume. The addition of small amount of polypropylene improved the mechanical properties of concrete. After reading much research concerning the importance of polypropylene fibers in improving the mechanical properties of reinforced concrete beams and roofs, the authors want to give a new study using this material to improve the tensile strength of reinforced concrete slabs and to make use of the advantages of these available materials in our country.

The importance or the advantage of results gained by the current study is to investigate the application of polypropylene fibre in slab since there were previous study used same type of fibre in beam and roof slab. A new percent of polypropylene was used in the present work in the tested slabs in order to study the effect of the fibre with percent less than 1.5 percent of cement by volume which was recommended in the previous work. Also, the dimensions of the selected slabs were somewhat did not used in the previous works.

Therefore, the aim of the of present paper is to evaluate and check out the performance and tensile strength of simply supported reinforced polypropylene fiber concrete slab under the effects of static loading in addition to evaluate the mechanical properties of fiber reinforced concrete. The parameters that taking into accounts are the polypropylene fiber percentages and compressive strengths of concrete for both normal and high strengths. Deflection, strength slab capacity and cracks propagations are the main parameters which were studied to evaluate the Behavior of reinforced concrete slab and the mechanical properties of concrete in the presence of polypropylene fiber.

2. Experimental Program

A lot of laboratory experiments were done in laboratories of structural engineering branch-department of Civil Engineering- University of Technology-Baghdad- Iraq to conduct the present research investigational job. A total of 27 cubes and 18 cylinders, standard control specimens have been casted and tested to examine the polypropylene fiber concrete properties, in addition to nine simply supported polypropylene reinforced concrete slabs were moulded and tested for evaluation of the effect of the polypropylene fiber on the structural performance of these slabs. All these slab specimens were with the same dimensions and geometry. These specimens are classified into three individual groups as per its compressive strength and the percentage of polypropylene fiber as will be explained later. The plan of present work was limited to 9 slab specimens only because each specimen was modelled to study the effects of one of the selected parameters (which were three different values for concrete compressive strength with three different percent of polypropylene for each compressive strength).

2.1. Concrete ingredients

2.1.1. Cement

Ordinary Portland cement Type I was used to cast all specimens (cube, cylinders, and slabs). The physical properties of the used Portland cement are matching with Iraqi specification No.5/1984[11]. Table 1 lists the physical cement properties.

Table 1. Portland cement physical properties.

Properties	Results	Iraqi specification, limits [11]
Specific surface area, m^2/kg	380	> 230.0
Time of setting by Vicat′s apparatus		
Initial, hour: minute	2:10	≥ 0.45 hours
Final, hour: minute	4:20	≤ 10.0 hours
"Compressive strength, MPa"		
3 days	21.7	> 15
7 days	30.4	> 23
Soundness, (%)	0.3	< 0.8

2.1.2. Polypropylene fiber

Concrete modification by using polymeric materials has been studied for the past four decades. In the present work, polypropylene was used to enhance the tensile properties of concrete. Polypropylene fiber could be defined as a low density synthetic fiber with low modulus of elasticity. It has a linear stress-strain relationship based on the monomer and manufactured from 85% of propylene. Polypropylene fibers are composed of crystalline and non-crystalline regions [10]. It is a light fibre, its density (0.91 gm/cm^3) is the lowest of all synthetic fibres. The mechanical properties of this fiber are listed in Table 2. Figure 1 shows the polypropylene fiber.

Fig. 1. Polypropylene fiber.

Table 2. Polypropylene fiber properties.

Length (mm)	Diameter (mm)	Density (kg/m^3)	Tensile strength (MPa)
12	0.016	900	400

2.1.3. Aggregate

Fine aggregate with a maximum size of 4.75 mm (zone 2 according to Iraqi specifications) and coarse aggregate with a size ranged between 5-19 mm are used for the required concrete mix design. The utilized fine and, coarse aggregate properties are complied with the Iraqi specification No.45/1984 [12] as publicized in Tables 3 and 4, respectively.

Table 3. Fine aggregate properties.

Sieve size (mm)	%Passing	Iraqi specification limits [12]
4.75	100.00	90-100
2.36	90.21	75-100
1.18	74.33	55-90
0.6	51.42	35-59
0.3	19.31	8-30
0.15	03.87	0-10
Specific gravity = 2.65 and Fineness modulus = 2.61		

Table 4. Coarse aggregate properties.

Sieve size (mm)	% Passing	Iraqi specification limit
20	100.00	100
14	100.00	90-100
10	82.10	50-85
5	05.98	0-10
Specific gravity = 2.62		

2.2. Concrete compressive strength

Several trial mixes were made to obtain the required concrete compressive strength. All the concrete mixes were designed according to the ACI 211.1-91 [13]. Three different values of compressive strengths are adopted in the present work, which is 30, 40 and 60 MPa in order to study the effect of polypropylene fiber on the normal to high strength concrete. The compositions for each mix design are presented in Table 5. A total of 27 concrete cubes (150×150×150) mm were used to determine the cube compressive strength of polypropylene fiber concrete in accordance with B.S 1881: part 116 [14] at a rate of three cubes for each mix. The specimens were tested by using 3000 kN ELE international digital hydraulic compressive testing machine until failure as shown in Fig. 2(a). The rate of loading was within the range (0.2 to 0.4) MPa/s according to the standard specifications. Also, 18 concrete cylinders with dimensions of ((150×300 mm)) are used to conduct cylindrical concrete compressive strength in accordance with ASTMC39/C 39M-16 Specification [15] . The digital hydraulic compressive testing machine used for the cube compressive strength was used also for obtaining the cylindrical compressive strength as shown in Fig. 2(b). In addition to that, another 18 cylinders (150*300) mm were utilized for splitting tensile strength test based on ASTM C496/C496M-11 specifications [16] using hydraulic jacks of 3000 kN with (0.94 kN/sec) loading rate increments as recommended by the specification. Cylinder vertical split failure mode was noticed on the tested specimens as clear in Fig. 3.

(a) Cube compressive strength test.

(b) Cylindrical compressive strength test.

Fig. 2. Compressive strength test.

Fig. 3. Splitting tensile strength test.

Table 5. Compositions of concrete mix design.

Materials	Compressive strength (MPa)		
	group-A	group-B	group-C
	30	**40**	**60**
Cement (kg/m³)	400	450	470
Fine aggregate (kg/m³)	760	775	620
Coarse aggregate (kg/m³)	980	1080	1280
Water (L/m³)	195	165	155
W/C	0.49	0.37	0.32
Super-plasticizer (Litter/100kg of cement)	------	4.5	7.1

As mentioned previously, a total of nine simply supported slab specimens were casted and tested in the present work to study the effect of polypropylene fiber in the tensile strength of RC slabs. These slab specimens were designed according to ACI 318M-19 code [17]. The slab specimens are classified into three groups according to its compressive strength and the percentage of polypropylene fiber. Table 6 illustrated the characteristics of these tested specimens. After concrete casting, slab specimens were remoulded after 24 hours and then placed in the water tank with an average temperature of 22 °C for 28 days curing time. All slab specimens are tested by hydraulic machine of 2500 kN full capacity which was available in structural Laboratory at University of Technology. The applied central point load and setup configuration of the slabs are shown in Fig. 4. Steel plate with dimensions of 485×485×25 mm was placed under the applied loading. The vertical displacements are measured by fixed dial gages which were located at the center of each specimen.

Table 6. The characteristics of tested specimens.

Group	Compressive strength*	Specimen Name	% Polypropylene fiber content
Group-A	30 MPa	S1	0.0
		S2	0.4
		S3	1.0
Group-B	40 MPa	S4	0.0
		S5	0.4
		S6	1.0
Group-C	60 MPa	S7	0.0
		S8	0.4
		S9	1.0

* These values of compressive strength are the target of our study which is the same as what we gained by trail mixes.

2.2.1. High range water reducing admixture (superplasticizer S.P.)

GLENIUM51 was used as a high-performance super plasticizing admixture in the present work. It is an admixture of a new generation based on modified polycarboxylic ether. The product has been primarily developed for the use in the concrete industry where the highest durability and performance is required. It is free of chloride and low in alkali and complies with the ASTM C494/C494M-15a [18].

2.3. Steel reinforcement details

All the tested slabs specimens have the same dimensions of 600 mm in width, 700 mm in length and 120 mm in thickness that were reinforced with the same bottom steel bars of ϕ6 mm at 150 mm center to center spacing as shown in Fig. 4. The reinforcement was tested to find out the yielding tensile strength; elongation and modulus of elasticity (see Fig. 5). The tensile test outcomes are recorded in Table 7. The tensile test was carried out based on ASTM A615/615M-14 specifications [19].

Table 7. Properties of steel bar.

Diameter (mm)	Yield streng (MPa)	Ultimate strength (MPa)	%Elongation
6	632.3	707	6.42

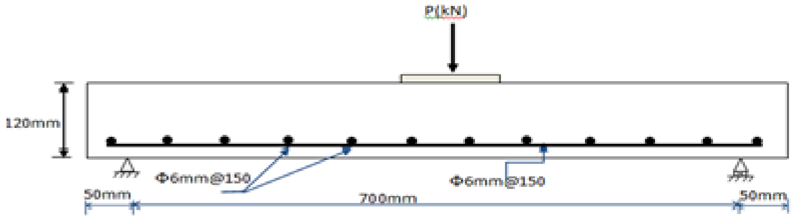

Fig. 4. Slab specimen details.

Fig. 5. Tensile steel bars test.

3. Test Results and Discussion

3.1. Compressive and tensile strength

Test results for the three different types of concrete are summarized in Table 8, noting that the obtained values represent the average of three standard specimens for each group. The presence of polypropylene fibers results in increasing in mortar components connection and hence increasing in concrete compressive strength as could be seen in Table 8. The splitting tensile strength was also proportionally increasing with the increase of the fiber percentage because these fibers enhanced the Behavior of concrete to resists more tension stresses due to applied loads as well as the presence of these fiber prevents cracks' propagations at early stages.

Table 8. Cylindrical compressive strength and tensile strength results.

Group name	compressive strength (MPa)	% Polypropylene fiber	Average compressive strength (MPa)	% Increase of compressive strength	Average tensile strength (MPa)	% Increase of tensile strength
Group A	30	0.0	30	-	2.7	---
		0.4	38.4	28.0	3.2	18.52
		1.0	40.8	36.0	3.3	22.22
Group B	40	0.0	40	-	3.1	-
		0.4	50.7	26.8	3.7	19.35
		1.0	54.1	35.3	3.8	22.58
Group C	60	0.0	60	-	4.1	-
		0.4	76.4	27.3	4.5	9.76
		1.0	78.8	31.3	4.7	14.63

3.2. Ultimate load capacity and deflections

Table 9 gives the results of ultimate load capacity for all the tested slab specimens. The highest value of ultimate load capacity was recorded for specimen S9 among all the tested slab specimens, which was equal to 495kN with increasing about 42%

in the ultimate capacity compared to S3 and about 21% compared to S6 (for the same percentage of polypropylene fiber). The experimental investigation shows that, the percentage increase in the ultimate loads for all the three groups is 14.1% (for S3) and 14.93% (for S6) and 17.86% (for S9) respectively compared to their control sample. The increase in the load carrying capacity as well as the good effect of polypropylene fiber on reducing concrete cracking may have related to the high tensile and pull-out strength of the fiber. The fibers even reduce the early plastic shrinkage cracking by enhancing the tensile capacity of fresh concrete to resist the tensile stresses caused by the typical volume changes. The fibre also distributes these tensile stresses more evenly throughout the concrete. Load-deflection relation may be substantial to describe the performance of the slabs under different phases of loads for different polypropylene fiber percentages.

Table 9. Ultimate loads results.

Group	Specimen name	Ultimate load (kN)	% Ratio of increase in ultimate load
Group-A	S1	305	---
	S2	330	8.2
	S3	348	14.1
Group-B	S4	355	-
	S5	375	5.63
	S6	408	14.93
Group-C	S7	420	-
	S8	480	14.29
	S9	495	17.86

Table 10 demonstrated the deflections and crack width values for all the tested slabs. The largest value of deflection was experienced by S7 with an increase about 48% in deflection and a decrease about 38% in the ultimate load compared with S1. It is noticed that, at the ultimate load, the deflection of the slab specimens decreases with the increase of percentage of polypropylene fiber for all the tested groups. Figures 6 and 7 demonstrate the comparative load-deflection and cracks width curves respectively for specimens S1, S2 and S3 of group A. The deflection curves of the slabs appeared to be identical in shape to their control one with different extremes. This comparison curves show that the high percentages of polypropylene fiber gave more strength capacity and more resistance to cracks developed and cracks propagations.

Table 10. Comparisons of maximum deflections and crack width.

Croup name	Specimen name	Maximum deflection (mm)	% Ratio of decrease in deflection	Crack width (mm)	% Ratio of decrease in crack width
Group-A	S1	10.2	---	0.87	---
	S2	9.1	10.78	0.78	10.4
	S3	7.8	23.53	0.61	29.9
Group-B	S4	12.1	-	0.91	-
	S5	10.7	11.57	0.80	12.09
	S6	9.5	21.49	0.74	18.68
Group-C	S7	15.10	-	1.20	-
	S8	14.00	7.28	1.00	16.67
	S9	12.90	14.57	0.88	26.67

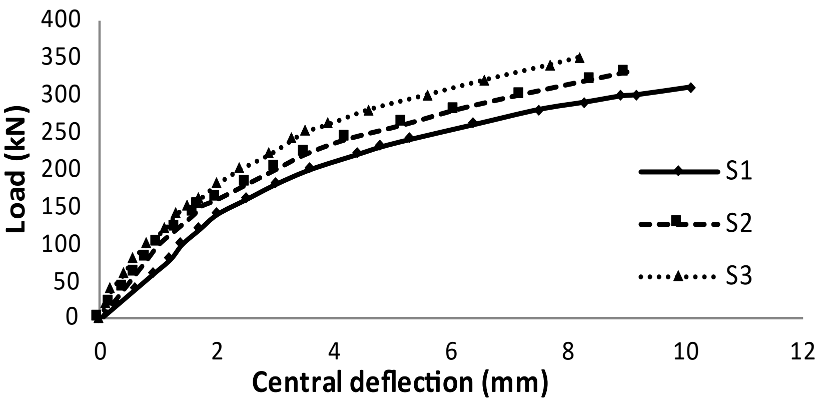

Fig. 6. Load-deflection curves for group A specimen.

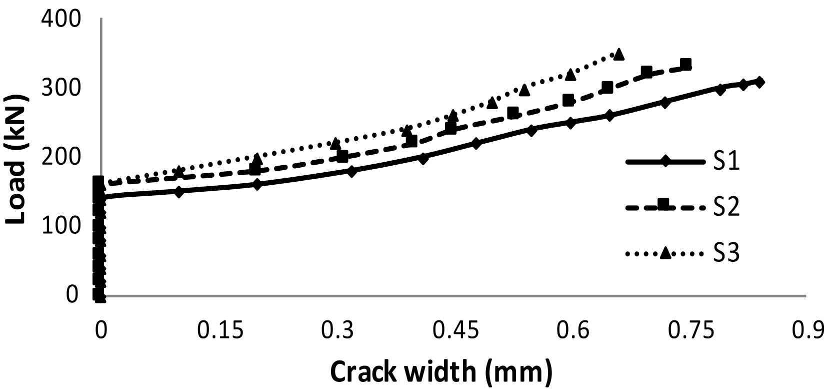

Fig. 7. Load-crack width curve for group A specimen.

Table10 shows the additional capacity gained by using polypropylene fiber. In addition to that, the use of these fibers leads to minimize the crack widths and improve the Behavior of the tested slabs. The used fiber plays their role in loads resisting capacity as could be seen in Table 9, in which the values of ultimate loads increase with the increase of fiber percentage for each group.

Similarly, Figs. 8 and 9 represent the load-deflection and cracks width respectively for specimens S4, S5 and S6 of group B. Figures 10 and 11 represent the load-deflection and cracks width respectively for specimens S7, S8 and S9 of group C. These curves show that the ductility increases with the increase in the percentage of polypropylene fibers as well as the values of deflection decreases. The load-deflection curves for all tested slabs were straight up to around 30% from the ultimate load and then the curve sloped to the horizontal direction because of cracks which lead to reduce the stiffness of the slabs.

The Behavior of the load-deflection becomes nonlinear as the Behavior and shape after the inflection point that represents the formation of plastic hinge and developed the first cracks up to failure. The inflection point becomes hinge in case of increasing the percentages of polypropylene fibers which means there is an enhancement in the tensile resistance and elastic deformation at service load.

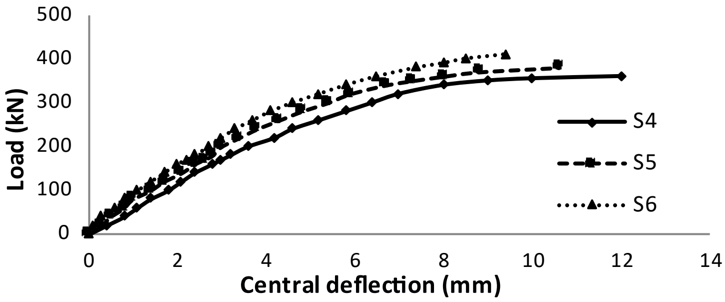

Fig. 8. Load- deflection curve of group B.

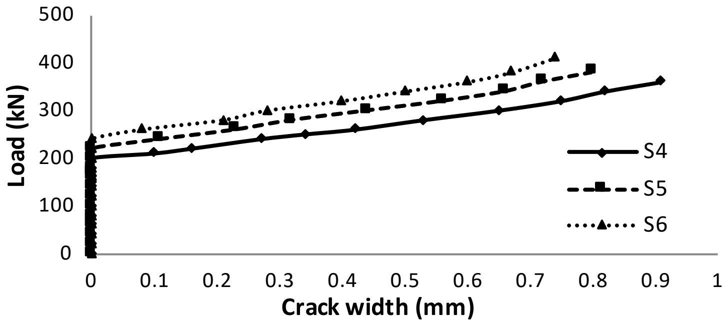

Fig. 9. Load- crack width curve of group B.

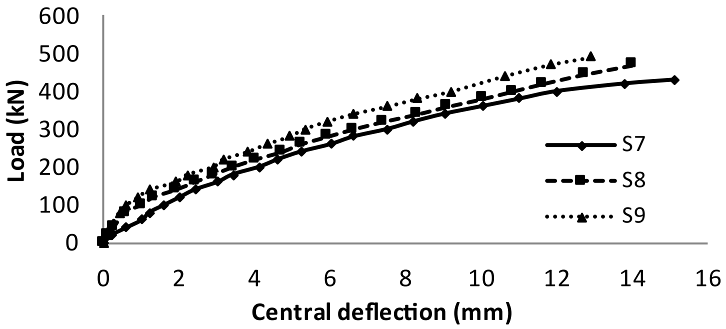

Fig. 10. Load- deflection curve of group C.

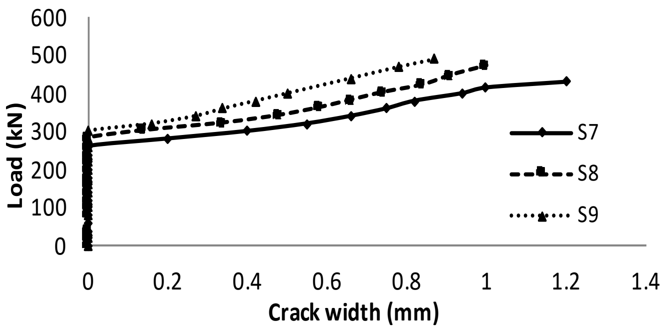

Fig. 11. Load- crack width Curve of group C.

3.3. Crack pattern and failure modes

Figures 12 to 14 display the cracks' propagations at the ultimate stage for groups A, B, and C, respectively. At premature stages of loading, all the tested slab specimens conducted in elastic manner and they were with no apparent cracks. Gradually, crack propagations were noticed for all tested specimens started from the applied load point and propagate to the external edges in the direction of the supports. The cracks approximately appear at an angle of 45^o. It is noticed that the cracks width and intensity decrease with the increase of the percentages of polypropylene fibers and compressive strength. Test results demonstrate that, the slab with higher compressive strength values gave more load capacity due to a significant reduction in block stress in compression zone. For example, as fiber content increased up to 1%, the load carrying capacity of the tested slab increases by about 14%, 15%, 18% for groups A, B and C, respectively. This is an indication to the effectiveness of the added fibers in improving the cracking resistance and minimizing the crack propagation. The presence of polypropylene fibers in the concrete mix delays the cracks appearance and width for all the three types of concrete compressive strengths, that is mean the modulus of rupture of the concrete increases due to an increase in the tensile strength and elastic deformation. The presence of polypropylene fiber with the high concrete compressive strength equipped a better dissemination for diagonal cracks all through the shear span in S6 and S9.

(a) Failure mode of S1. (b) Failure mode of S2. (c) Failure m ode of S3.

Fig. 12. Failure modes of group A.

(a) Failure mode of S4. (b) Failure mode of S5. (c) Failure mode of S6.

Fig. 13. Failure modes of group B.

(a) Failure mode of S7. **(b) Failure mode of S8.** **(c) Failure mode of S9.**

Fig. 14.Failure modes of group C.

4. Conclusion and Recommendations

A series of experimental works were completed to investigate polypropylene fiber effect on compressive, tensile strength and load capacity of fiber reinforced concrete slab specimens. The following conclusions have been drawn by this laboratory work:

- The presence of polypropylene fibers with the concrete mortars affect the concrete mechanical properties, strength capacity, deflections, and cracks width of the slabs. The test results show that adding polypropylene fibers increases the compressive strength and decreases the cracks width, in addition to increasing the strength capacities of the reinforced concrete slab. These properties are improved with an increase of fibers percentages.
- The experimental results showed a noticeable increase in concrete strength because of utilization of fiber which also works as crack bridging. The increasing in compressive strength for fibrous concrete as compared with non-fibrous concrete for 30 MPa compressive strength is 28% and 36 % for 0.4% and 1.0% fiber content, respectively. While for 40 MPa compressive strength, the percentage of increase was about 26.8% and 35.3% for 0.4% and 1.0% fiber contents, respectively. For 60 MPa compressive strength, the percentage of increase of the compressive strength was about 27.3% and 31.3% respectively.
- Increasing the compressive strength because of polypropylene fibers led to an increase in the modulus of elasticity and hence a noticeable decline in the deflection values. Also, the crack width will reduce because the presence of polypropylene fibers increases the resistance of section against the tensile stress that is mean there is an enhancement in the tension zone and elastic deformation.
- Polypropylene fibers a steel material enhances the tensile strength of concrete so that it can resists more tension stresses due to applied loadings. The increase in splitting tensile strength for the 30 MPa was about 18.52 and 22.22% as the percentage of polypropylene increased by 0.4 and 1.0% respectively compared to its control one. While for 40 MPa, the percentage of increasing in the tensile strength was about 19.35 and 22.58%. For 60 MPa, the percentage of increasing in the tensile strength was about 9.76 and 14.63% respectively.

- The flexural strength capacity of the slab increases as the compressive strength and the percentages of polypropylene fibers increase due to a significant reduction in compression part of the slab and this means an increase in their curvature ductility that leads to an increase in the moment capacity or in another word, an increase in the load capacity of the concrete section as could be seen in Table 10. The maximum increase in the load capacities were about 14%, 15% and 17% for 30 MPa, 40 MPa, and 60 MPa, respectively.
- It was concluded from the present work that the polypropylene fiber has a good effect to enhance the tensile strength of concrete even when its percentage was less than 1.5 % of cement which was recommended in the previous work.
- Studying the effect of different percentages of polypropylene fiber on the tensile behaviour of reinforced concrete is recommended in order to find the optimum fiber content.

Nomenclatures

fc'	Specified compressive strength of concrete, MPa
f_t	Tensile strength of concrete, MPa

Abbreviations

ASTM	American Society for Testing Material
BS	British Standard Institution
IQS	Iraqi Specification

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