Mechanical Properties of Crimped Polypropylene Fiber-Reinforced Concrete

Omar Mansour [1], Ezz El-Din Mostafa [2], Ibrahim Abdel-Latif [3], Ayman Khalil[4]

Abstract— This paper investigates the influence of the addition of various proportions of crimped polypropylene fibers on the mechanical properties of hardened concrete. The objectives of this study are to find the optimum dosage of polypropylene fibers between 2.5 to 8 kg per cubic meter of concrete and investigate the effect of the optimum dosage on the mechanical properties of different concrete mixtures. An experimental program was carried out to investigate the influence of polypropylene fibers on the properties of hardened concrete. Concrete specimens have been tested at different ages to determine the mechanical properties of concrete, namely, compressive strength, tensile splitting strength, flexural strength, and direct tensile strength. Samples with polypropylene fibers dosage of 2.5 kg/m³ showed the best results. The compressive, split tensile and flexural strengths improved significantly with an increase in strength up to 53, 45 and 40%, respectively.

Index Terms— Polypropylene Fibers (PPF), Fiber-Reinforced Concrete (FRC), Mechanical Properties, Compressive Strength, Tensile Splitting Strength, Flexural Strength, Direct Tensile Strength.

1 Introduction

Fiber reinforced concrete is gaining attention as an effective means of improving the performance of concrete. Deficiences in conventional concrete, such as low tensile strength and poor toughness, promoted the development of FRC in recent years. FRC can be defined as a composite material produced by reinforcing conventional concrete with randomly distributed fibers. When the fibers are distributed in a homogeneous way and used in an appropriate quantity inside the concrete, they reduce cracks, contribute to tensile strength, toughness, ductility, durability and improve other mechanical properties. Many researchers have studied the effect of polypropylene fibers on the mechanical properties of concrete.

Abdulnasser Abbas et al. (2011) [1] investigated the effect of adding the polypropylene fibers (0.4, 0.8, 1.0 and 1.5% of cement content) on the compressive and flexural strength of concrete. The results showed that the mechanical properties (compressive and flexural strengths) were improved significantly. The compressive strength increased by 64% and the flexural strength increased by about 55.5%. Samples with fibers content of 1.5% showed optimum results.

Mohammad Jobaer et al. (2011) [2] stated that the addition of polypropylene fibers enhanced the compressive strength insignificantly. Polypropylene fibers at 0.33, 0.42 and 0.51% volume fractions improved the tensile strength by at least 10, 15, and 14%, respectively. Similarly, fibers improved the ultimate strain value by at least 50, 60, and 60% for macro fibers of 0.33, 0.42, and 0.51% volume fractions, respectively.

Saeid Kakooei et al. (2012) [3] examined the effect of polypropylene fiber on the compressive strength of concrete. Different fiber amounts 0, 0.5, 1, 1.5, and 2 kg/m³ were used. The samples with added polypropylene fibers of 1.5 kg/m³ showed better results compared to the others, as the compressive strength increased by 48%.

Kolli.Ramujee (2013) [4] studied the compressive strength and the splitting tensile strength of concrete samples made with different fibers amounts vary from 0%,0.5%,1% 1.5% and 2.0%. The samples with added PPF of 1.5 % showed optimum results.

Saman Khan et al. (2015) [5] conducted a comparative experimental study on two grades of concrete mixes (25 MPa and 30 MPa) with different volume fractions of polypropylene fibers (0.0%, 0.5%. 1.0%, 1.5%, 2.0%, 2.5% and 3.0%). There was a significant improvement in both compressive and tensile strengths for concrete mixes reinforced with PPF. The samples with added PPF of 1% and 1.5% showed the best results. The compressive strength gained by polypropylene fibers was observed to decrease by increasing the cement content; the increase in cement content while increasing the percentage of fibers caused the strength to decrease even greater.

Ridha Nehvi et al. (2016) [6] carried out tests to determine the mechanical properties of concrete for compressive strength, split tensile strength and flexural strength with polypropylene fibers in the proportion of 0.0%, 0.1%, 0.2%, 0.3%, 0.4%, and 0.5% by volume of concrete. The workability of the FRC has been found to decrease with the increase of the fibers percentage in the concrete mix. The maximum increase in compressive strength was 23.38% at 0.5% fiber content, split tensile strength was 14.84% at 0.3% fiber content, and flexural strength was 37.27% at 0.3% fiber content.

Siddiqi Z.A. et al. (2018) [7] investigated different samples of concrete containing different dosages of polypropylene fibers (0.1%, 0.2%, 1% and 2% of the total concrete volume). Maximum

1 *M.Sc. Student, Structural Engineering Department, Ain Shams University, Egypt. E-mail: omar.a.mansour0@gmail.com*
2 *Assistant Professor, Structural Engineering Department, Ain Shams University, Egypt. E-mail: ezzeldin.mostafa@eng.asu.edu.eg*
3 *Assistant Professor, Structural Engineering Department, Ain Shams University, Egypt. E-mail: ibrahim.yousif@eng.asu.edu.eg*
4 *Professor, Structural Engineering Department, Ain Shams University, Egypt. E-mail: ayman.hussein.khalil @eng.asu.edu.eg*

efficiency from the material was obtained at 0.2% dosage of fibers. Below and above this percentage, the flexural and compressive strengths start to decrease. The compressive strength increased by 8.93% and tensile strength increased by 14.27% for samples with polypropylene fibers 0.2%.

Recently, different types of fibers have been used in many applications of concrete. Steel fibers are one of the most known fibers used to enhance the mechanical properties of concrete, but factors such as durability concerns and high cost may help to promote polypropylene fibers (PPF) as a valid alternative to steel fibers. PPF are durable, sustainable, non-corrosive and low cost compared to steel fibers.

The experimental work in this paper is a part of an extended experimental and numerical study on the punching shear of the internal flat slab column connection when using high strength polypropylene fiber reinforced concrete. Therefore, the present experimental work aims to study the mechanical properties of fiber-reinforced concrete with variable dosages of PPF and different concrete mixtures.

2 Methodology

The present study consists of a comparative experimental study of the addition of polypropylene fiber on the mechanical properties of concrete. Three concrete mixtures with different dosages of polypropylene fibers were designed to achieve target compressive strengths of 25, 40, and 50 MPa after 28 days. For concrete mixture with a target compressive strength of 25 MPa, a total of five batches of the concrete mix were prepared which consisted of one control mix without polypropylene fibers and four mixes with different dosages of polypropylene fibers (2.5, 4, 6 and 8 kg/m^3 of concrete). For concrete mixture with target compressive strengths of 40 and 50 MPa, a total of two batches of the concrete mix were prepared for each mixture, which consisted of one control mix without polypropylene fibers and one mix with the optimum dosage of polypropylene fibers.
Six (150x150x150 mm) cubes, three (150 mm diameter and 300 mm height) cylinders, three (100x100x500 mm) prisms, and three (100x100x500 mm) reinforced prisms were prepared for each batch of the concrete mixture. Tests had been carried out to study the mechanical behavior of polypropylene fiber reinforced concrete, such as compressive strength test, tensile splitting strength test, flexural strength test and direct tension test.

3 Experimental program

The experimental study of the current research consists of two phases. The following are the details of the two phases.

- **Phase (I)**

This phase included casting five batches of concrete mix with a target compressive strength of 25 MPa consisting of one control mix without polypropylene fibers and four mixes with different dosages of polypropylene fibers (2.5, 4, 6, and 8 kg/m^3 of concrete). The main objective of this phase was to investigate the effect of the addition of polypropylene fibers on the mechanical properties of concrete and to obtain the optimum fibers dosage.

- **Phase (II)**

This phase included casting two batches for each concrete mix with target compressive strengths of 40 and 50 MPa consisting of one control mix without polypropylene fibers and one mix with the optimum dosage of polypropylene fibers obtained from Phase (I). The main objective of this phase was to investigate the effect of polypropylene fibers on the mechanical properties of concrete using different concrete mixes for different target compressive strengths.

4 Mix design

The concrete mixes were designed to achieve a target compressive strength of 25, 40 and 50 MPa after 28 days. The mixes proportions were given in Table (1).

TABLE 1: CONCRETE MIX CONSTITUENTS FOR 1 m³ OF FRESH CONCRETE

Mix ID	Target Compressive Strength (MPa)	Cement (kg)	Aggregate (kg)		Water (lit)	Admix. (lit)
			Coarse	Fine		
F25	25	350	1050	800	200	3.5
F40	40	455	1145	615	205	9
F50	50	500	1075	715	150	15

The used cement was ordinary Portland cement that complies with the requirement of the Egyptian standard specifications, [9]. The used coarse aggregate was crushed stone. The used sand was natural sand with a fineness modulus of 2.47. Superplasticizer was used with the recommended dosages supplied by the manufacturer to overcome the workability issues. Polypropylene fibers were added to the concrete mix with dosages of 2.5, 4, 6, and 8 kg per volume of concrete according to the requirement of each batch in the two phases. The used PPF were formed into a crimped profile in order to anchor it in a cementitious matrix. The physical properties of polypropylene fibers were given in Table (2).

TABLE 2: PHYSICAL PROPERTIES OF POLYPROPYLENE FIBERS

Density (g/cm³)	Length (mm)	Diameter (mm)	Aspect ratio	Tensile Strength (MPa)	Elastic Modulus (GPa)
0.91	48	0.85	56.5	400	4.7

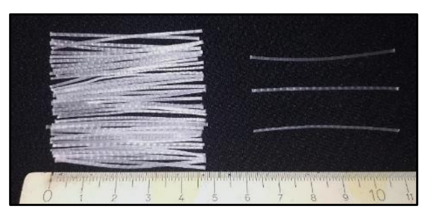


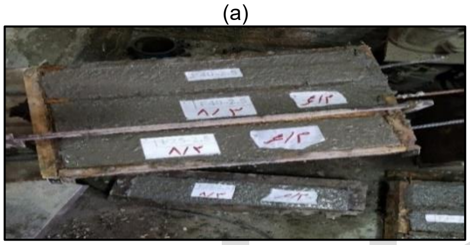
Fig. 1. Shape of used polypropylene fibers

5 Casting and curing of specimens

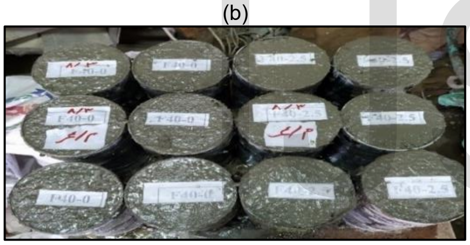
All mixes were batched in a tilting pan type mixer, as shown in Fig. (2). A thin layer of mineral oil was used to coat the internal surfaces of the molds before casting directly. Fresh concrete was poured into the molds and compacted using a standard compacting rod, as shown in Fig. (3). All the concrete specimens were demolded after 24 hours and then cured in a water tank till reaching the age of test at 7 and 28 days, as shown in Fig. (4).

Fig. 2. Tilting pan type concrete mixer

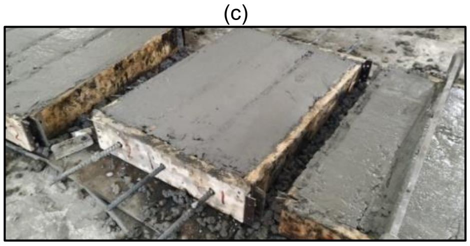
(a)



(b)



(c)



(d)

Fig. 3. Poured specimens after compacting

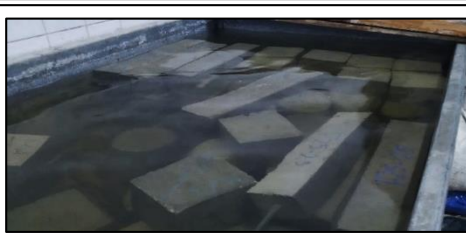


Fig. 4. Curing of specimens in a water tank

6 Test Results and Discussion

The discussions of test results for the specimens (compressive strength test, tensile splitting strength test, flexural strength test, and direct tension test) are summarized below.

6.1 Compressive strength Test

A total of 54 concrete cube specimens of dimensions 150 mm x 150 mm x 150 mm were tested to determine the compressive strength as per BS 1881: Part 115. Each batch consisted of six cubes, where three cubes were tested at the age of 7 days, and the other three cubes were tested at the age of 28 days. The values of mean compressive strengths at ages 7, 28 days were given in Table (3).

TABLE 3: MEAN COMPRESSIVE STRENGTH TEST RESULTS AT THE AGE OF 7 AND 28 DAYS

Phase No.	Mix ID	Fibers dosage (kg/m³)	f_{cu}^* (MPa)		Enhancement (%)		Remarks
			7 days	28 days	7 days	28 days	
I	F25	0	20.20	25.20	-	-	Control
		2.5	34.00	38.60	68	53	-----
		4	27.20	37.30	34	48	-----
		6	22.60	26.80	12	6	-----
		8	19.80	25.80	-2	2	-----
II	F40	0	35.10	40.50	-	-	Control
		2.5	35.60	40.80	2	1	-----
	F50	0	45.70	50.30	-	-	Control
		2.5	45.00	51.80	-2	3	-----

* Mean compressive strength f_{cu} was determined as the arithmetical mean of 3 specimens.

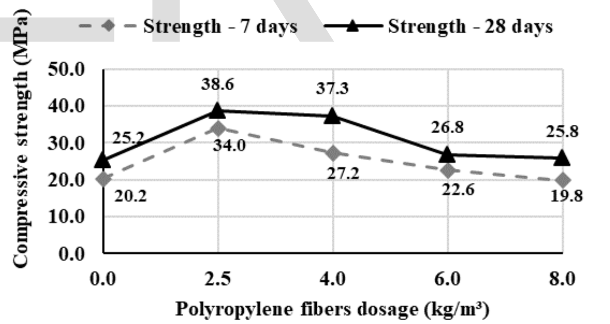


Fig. 5. Mean compressive strengths vs. polypropylene fibers dosage for F25 mix at the age of 7 and 28 days

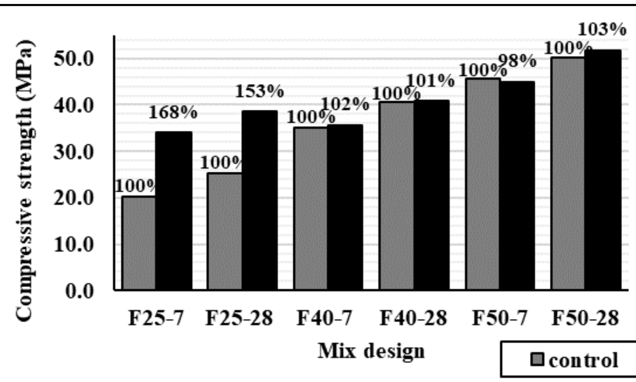


Fig. 6. Mean compressive strengths for F25, F40, and F50 mixes with polypropylene fibers dosage 2.5 kg/m³ at the age of 7 and 28 days

Fig. 7. Failure section for control cube without polypropylene fibers

Fig. 8. Failure section for cube with polypropylene fibers

Based on the calculated values of mean compressive strength, which are represented graphically in Fig. (5 & 6), the following points were observed:

- At the age of 7 days, the mean compressive strength of mixes F25 with 2.5, 4, and 6 kg/m³ dosages of the PPF are 68, 34 and 12 % respectively higher than that of the control mix. Also, at the age of 28 days, the mean compressive strength of mixes F25 with 2.5, 4, 6 and 8 kg/m³ dosages of the PPF are 53, 48, 6 and 2 % respectively higher than that the control mix.
- At the age of 7 days, the mean compressive strength of mixes with 2.5 kg/m³ dosage of the PPF F25 and F40 are 68, and 2 % respectively higher than that of the control mix. Also, at the age of 28 days, the mean compressive strength of mixes with 2.5 kg/m³ dosage of the PPF F25, F40 and F50 are 53, 1, and 3 % respectively higher than that the control mix.

Generally, the increase in the dosages of PPF showed an improvement in the compressive strength for concrete mixes F25. The dosage of PPF 2.5 kg/m³ is the optimum dosage of concrete mixes F25. However, adding the PPF in concrete mixes F40 and F50 showed a slight improvement in the compressive strength.

6.2 Tensile splitting strength test

A total of 27 concrete cylinder specimens of dimensions 150 mm diameter and 300 mm height were tested to determine the tensile splitting strength as per BS 1881: Part 117. Each batch consisted of three cylinders tested at the age of 28 days. The values of mean tensile splitting strength at age 28 days were given in Table (4).

TABLE 4: MEAN TENSILE SPLITTING STRENGTH TEST RESULTS AT THE AGE OF 28 DAYS

Phase No.	Mix ID	Fibers dosage (kg/m³)	f_{ts}* (MPa)	Enhancement (%)	Remarks
I	F25	0	2.20	-	Control
		2.5	3.20	45	-----
		4	2.90	32	-----
		6	2.40	9	-----
		8	2.30	5	-----
II	F40	0	2.70	-	Control
		2.5	2.90	8	-----
	F50	0	3.10	-	Control
		2.5	3.70	19	-----

* Mean tensile splitting Strength f_{ts} was determined as the arithmetical mean of 3 specimens.

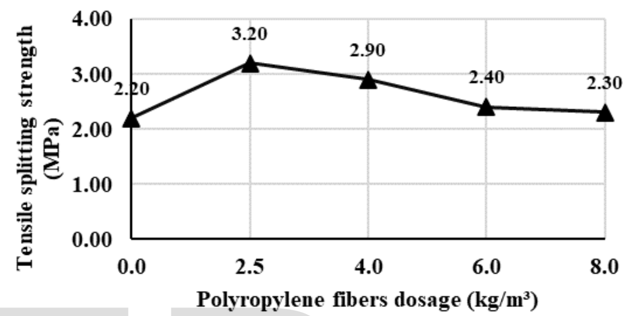


Fig. 9. Mean tensile splitting strengths vs. polypropylene fibers dosage for F25 mix at the age of 28 days

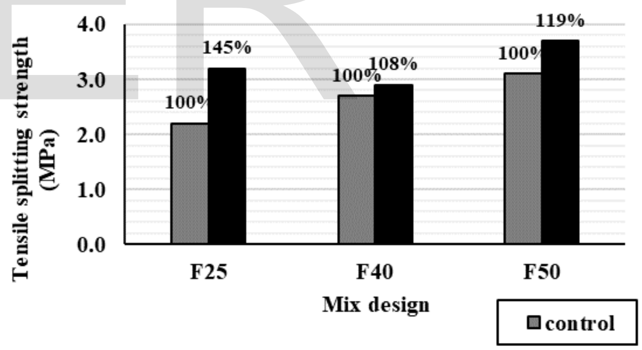


Fig. 10. Mean tensile splitting strength for F25, F40, and F50 mixes with polypropylene fiber dosage 2.5 kg/m³ at the age of 28 days

Fig. 11. Failure section for control cylinders without polypropylene fibers

Fig. 12: Failure section for cylinders with polypropylene fibers

Based on the calculated values of mean tensile splitting strength, which are represented graphically in Fig. (9 & 10), the following points were observed:

- The mean tensile splitting strength of mixes F25 with 2.5, 4, 6 and 8 kg/m³ dosages of the PPF are 45, 32, 9 and 5 % respectively higher than that of the control mix.
- The mean tensile splitting strength of mixes with 2.5 kg/m3 dosage of the PPF F25, F40 and F50 are 45, 8, and 19 % respectively higher than that of the control mix.

Generally, the increase in the dosages of PPF showed an improvement in the tensile splitting strength for concrete mixes F25. The dosage of PPE 2.5 kg/m³ is the optimum dosage of concrete mixes F25. Also, adding the PPF in concrete mixes F40 and F50 showed an improvement in the tensile splitting strength.

6.3 Flexural strength test

A total of 27 concrete prism specimens of dimensions 100 mm x 100 mm x 500 mm were tested to determine the rupture strength as per ISO 4013. Each batch consisted of three prisms tested at the age of 28 days. The values of mean rupture strength at age 28 days were given in Table (5).

TABLE 5: MEAN RUPTURE STRENGTH TEST RESULTS AT THE AGE OF 28 DAYS

Phase No.	Mix ID	Fibers dosage (kg/m³)	f_r^* (MPa)	Enhancement (%)	Remarks
I	F25	0	3.80	-	Control
		2.5	5.30	40	-----
		4	5.10	34	-----
		6	4.20	11	-----
		8	4.10	8	-----
II	F40	0	4.70	-	Control
		2.5	5.40	15	-----
	F50	0	5.10	-	Control
		2.5	5.70	12	-----

* Mean rupture strength f_r was determined as the arithmetical mean of 3 specimens.

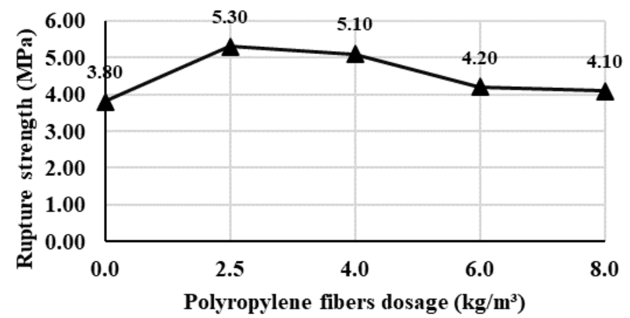


Fig. 13. Mean rupture strength vs. polypropylene fibers dosage for F25 mix at the age of 28 days

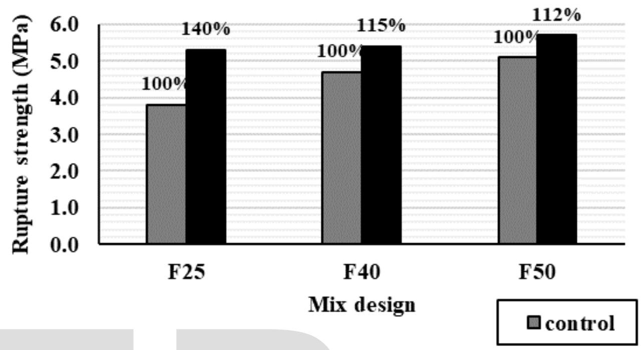


Fig. 14. Mean rupture strength for F25, F40 and F50 mixes with optimum polypropylene fibers dosage 2.5 kg/m³ at the age of 28 days

Fig. 15. Failure section for control prisms without polypropylene fibers

Fig. 16. Failure section for prisms with polypropylene fibers prisms

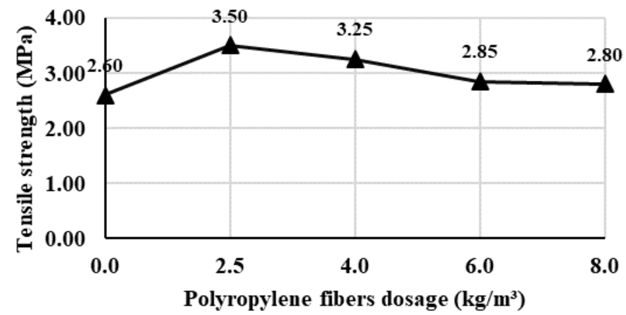


Fig. 17. Mean tensile strength vs. polypropylene fibers dosage for F25 mix at the age of 28 days

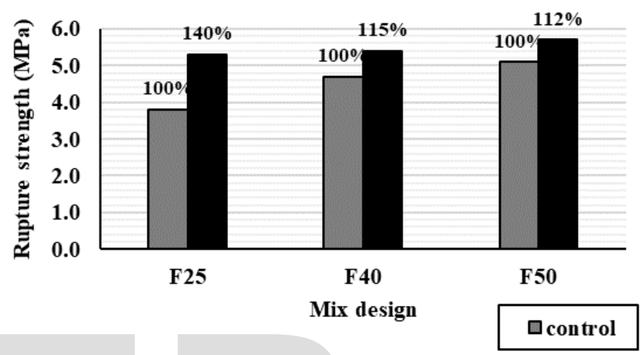


Fig. 18. Mean tensile strength for F25, F40, and F50 mixes with optimum polypropylene fibers dosage 2.5 kg/m³ at the age of 28 days


Fig. 19. Failure section for control prisms without polypropylene fibers

Based on the calculated values of mean rupture strength, which are represented graphically in Fig. (13 & 14), the following points were observed:

- The mean rupture strength of mixes F25 with 2.5, 4, 6 and 8 kg/m³ dosages of the PPF are 40, 34, 11 and 8 % respectively higher than that of the control mix.
- The mean rupture strength of mixes with 2.5 kg/m³ dosage of the PPF F25, F40 and F50 are 40, 15, and 12 % respectively higher than that of the control mix.

Generally, the increase in the dosages of PPF showed an improvement in the rupture strength for concrete mixes F25. The dosage of PPF 2.5 kg/m³ is the optimum dosage of concrete mixes F25. Also, adding the PPF in concrete mixes F40, and F50 showed an improvement in the rupture strength.

6.4 Direct tension test

A total of 27 reinforced concrete prism specimens of dimensions 100 mm x 100 mm x 500 mm were tested to determine the tensile strength. Each batch consisted of three prisms tested at the age of 28 days. The values of mean tensile strength at age 28 days were given in Table (6).

TABLE 6: MEAN TENSILE STRENGTH TEST RESULTS AT THE AGE OF 28 DAYS

Phase No.	Mix ID	Fibers dosage (kg/m³)	f_t^* (MPa)	Enhancement (%)	Remarks
I	F25	0	2.60	-	Control
		2.5	3.50	35	-----
		4	3.25	25	-----
		6	2.85	10	-----
		8	2.80	8	-----
II	F40	0	3.30	-	Control
		2.5	3.75	14	-----
	F50	0	3.55	-	Control
		2.5	3.90	10	-----

* Mean tensile strength f_t was determined as the arithmetical mean of 3 specimens.

ISSN 2229-5518

Fig. 20. Failure section for prisms with polypropylene fibers

Based on the calculated values of mean tensile strength, which are represented graphically in Fig. (17 & 18), the following points were observed:

- The mean tensile strength of mixes F25 with 2.5, 4, 6 and 8 kg/m³ dosages of the PPF are 35, 25, 10 and 8 % respectively higher than that of the control mix.
- The mean rupture strength of mixes with 2.5 kg/m³ dosage of the PPF F25, F40 and F50 are 35, 14, and 10 % respectively higher than that of the control mix.

Generally, the increase in the dosages of PPF showed an improvement in the tensile strength for concrete mixes F25. The dosage of PPF 2.5 kg/m³ is the optimum dosage of concrete mixes F25. Also, adding the PPF in concrete mixes F40, and F50 showed an improvement in the tensile strength.

Finally, the addition of PPF to concrete improved the mechanical properties of concrete due to the following:

a. The PPFs acted as anchors between the cement paste and the fine and coarse aggregates, which increased the durability of concrete before failure. The compressive strength increased due to fiber and aggregate bonding and not due to cement paste bonding.

b. The PPFs stop the propagating of cracks by holding the cement matrix together or bridge the cracks. So, the cracks cannot grow longer and wider and propagate gradually.

c. The PPFs may reduce the early plastic shrinkage cracking. However, according to T. Budi Aulia [8], the gain of mechanical properties of concrete may be lost due to the fact that the fibers increase the pore volume of concrete by creating more micro-defects in the cement matrix. This can emphasize that the addition of fibers beyond the optimum dosage may reduce the contribution of interfacial bond strength provided by matrix, which results in poor stress redistribution.

7 Comparison between Experimental Results and Code Provisions

The experimental results of modulus of rupture are compared with the empirical values predicted by the Egyptian Code of Practice ECP 203-2018 [9] and American Concrete Institute ACI 318-19 [10] and are recorded in Table (7).

According to the ECP 203-2018, the modulus of rupture for concrete is calculated using the following equation:

$$f_{r\,ECP} = 0.6\sqrt{f_{cu}}\,* \quad N/mm^2$$

*Cube compressive strength f_{cu} is given in Table (3).

According to the ACI 318-19, the modulus of rupture for concrete is calculated using the following equation:

$$f_{r\,ACI} = 0.62\lambda\sqrt{f'_c}\,** \quad N/mm^2$$

λ = 1 for normal concrete

**Cylinder compressive strength f'_c is calculated as 0.8 f_{cu}.

TABLE 7: COMPARISON BETWEEN EXPERIMENTAL RESULTS AND EMPIRICAL RESULTS FOR MODULUS OF RUPTURE

Mix ID	Fibers dosage (kg/m³)	Experimental (MPa)					Experimental / Empirical Ratio*					
		f_{ts}	f_r	f_t	$f_{r\,ECP}$	$f_{r\,ACI}$	f_{ts}/f_r ECP	f_r/f_r ECP	f_t/f_r ECP	f_{ts}/f_r ACI	f_r/f_r ACI	f_t/f_r ACI
F25	0	2.20	3.80	2.60	3.01	2.80	0.72	1.26	0.86	0.78	1.36	0.93
	2.5	3.20	5.30	3.50	3.73	3.54	0.85	1.42	0.94	0.89	1.50	0.99
	4	2.90	5.10	3.25	3.66	3.41	0.79	1.39	0.89	0.84	1.50	0.95
	6	2.40	4.20	2.85	3.10	2.96	0.78	1.35	0.92	0.81	1.42	0.96
	8	2.30	4.10	2.80	3.05	2.86	0.74	1.34	0.92	0.79	1.43	0.98
F40	0	2.70	4.70	3.30	3.82	3.53	0.70	1.23	0.86	0.76	1.33	0.93
	2.5	2.90	5.40	3.80	3.83	3.54	0.75	1.41	0.98	0.81	1.53	1.06
F50	0	3.10	5.10	3.60	4.25	3.93	0.72	1.20	0.84	0.78	1.30	0.90
	2.5	3.70	5.70	3.90	4.32	3.99	0.85	1.32	0.90	0.92	1.43	0.98

* Ratio was determined by dividing the experimental strength with the empirical strength predicted by ECP 203-2018 and ACI 318-19.

Both ECP 203-2018 and ACI 318-19 provided accurate predictions for the tensile strength recorded experimentally by direct tension test for both the control specimens without fibers and the specimens with fibers.

8 Conclusion

Based on the experimental investigations and analysis, the following conclusions can be drawn:

a. Polypropylene fiber enhanced the compressive strength, tensile splitting strength, rupture strength, and direct tensile strength when added to concrete. Specimens with polypropylene fibers dosage of 2.5 kg/m³ showed the best results. With a higher percentage of polypropylene fibers, the strength decreased as the volume of pores increased, which created micro defects in the cement matrix.

b. The addition of polypropylene fibers had a significant effect on the compressive strength for F25 mix. Compressive strength compared to control specimen without fibers at the age of 28 days increased by 53, 48, 6, and 2% for polypropylene fiber dosages 2.5, 4, 6, and 8 kg/m³, respectively.

c. The addition of polypropylene fibers had no significant effect on the compressive strength for F40 and F50 mixes. The compressive strength for specimens with polypropylene fibers

2.5 kg/m³ increased by 1 and 3% for F40 and F50 mixes, respectively, compared to control specimen without fibers.

d. The split tensile strength increased significantly with the addition of polypropylene fibers. The split tensile strength compared to the control specimen without fibers increased up to 45, 8, and 19% for F25, F40 and F50 mixes, respectively.

e. The rupture strength increased significantly with the addition of polypropylene fibers. The rupture strength compared to control specimen without fibers increased up to 40, 15, and 12% for F25, F40 and F50 mixes, respectively.

f. The tensile strength increased significantly with the addition of polypropylene fibers. The tensile strength compared to the control specimen without fibers increased up to 35, 14, and 10% for F25, F40 and F50 mixes, respectively.

g. The empirical expressions stated by both ECP 203-2018 and ACI 318-19 can be used to predict the tensile strength for specimens with or without PPF.

REFERENCES

[1] Ne'ma, Najaat H., Abdulnasser M. Abbas, and Rana A. Mtasher. "Strength prediction of polypropylene fiber reinforced concrete." Engineering and Technology Journal 29, no. 2 (2011): 305-311.

[2] Hasan, M. J., M. Afroz, and H. M. I. Mahmud. "An experimental investigation on mechanical behavior of macro synthetic fiber reinforced concrete." Int. J. Civ. Environ. Eng 11, no. 3 (2011): 19-23.

[3] Kakooei, Saeid, Hazizan Md Akil, Morteza Jamshidi, and Jalal Rouhi. "The effects of polypropylene fibers on the properties of reinforced concrete structures." Construction and Building Materials 27, no. 1 (2012): 73-77.

[4] Ramujee, Kolli. "Strength properties of polypropylene fiber reinforced concrete." International Journal of Innovative Research in science, engineering and technology 2, no. 8 (2013): 3409-3413.

[5] Khan, Saman, Roohul Abad Khan, Amadur Rahman Khan, Misbahul Islam, and Saman Nayal. "Mechanical Properties of Polypropylene fibre reinforced concrete for M25 and M 30 mixes: A Comparative Study." International Journal of Scientific Engineering and Applied Sciences 1, no. 6 (2015).

[6] Ridha Nehvi, Prashant Kumar, Umar Zahoor Nahvi, 2016, Effect of Different Percentages of Polypropylene Fibre (Recron 3s) on the Compressive, Tensile and Flexural Strength of Concrete, INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT) Volume 05, Issue 11 (November 2016).

[7] Siddiqi, Z. A., M. M. Kaleem, M. Usman, M. Jawad, and A. Ajwad. "Comparison of Mechanical Properties of Normal & Polypropylene Fiber Reinforced Concrete." Journal DOI: https://doi. org 2, no. 1 (2018).

[8] Aulia, T. Budi. "Effects of polypropylene fibers on the properties of high-strength concretes." Institutes for Massivbau and Baustoffechnologi, University Leipzig, Lacer 7 (2002).

[9] Egyptian Code for design and Construction of reinforced concrete structures ECP 203-2018, Egypt, (2018).

[10] ACI Committee 318. "Building Code Requirements for Structural Concrete (ACI 318-19): An ACI Standard: Commentary on Building Code Requirements for Structural Concrete (ACI 318R-19)." American Concrete Institute, 2019.