Scientific Review Engineering and Environmental Sciences (2023), 32 (4), 320–337

Sci. Rev. Eng. Env. Sci. (2023), 32 (4) https://srees.sggw.edu.pl

ISSN 1732-9353 (suspended) eISSN 2543-7496 DOI 10.22630/srees.5218

Received: 06.08.2023
Accepted: 10.10.2023

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Enhancement of tensile performance of concrete by using synthetic polypropylene fibers

Keywords: polypropylene fiber, modulus of rupture, toughness

Introduction

Concrete is a material commonly used for construction, consisting of a mixture of aggregates, water, and cement. This material exhibits suitability for a wide range of structural applications, including but not limited to buildings, bridges, roads, and dams. The utilization of concrete in construction is highly preferred due to its remarkable compressive strength and durability. Concrete exhibits a very low tensile strength, which is a fundamental behavior that makes it vulnerable to cracking when subjected to tensile stresses. This limitation often necessitates using reinforcements to improve the tensile performance of concrete structures and maintain their structural integrity under service loads. Improving the tensile strength of the concrete matrix can effectively mitigate the probability of struc-

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tural elements developing cracks. The concept prevents corrosion by insulating reinforcement steel from moisture and the atmosphere. Several techniques have been investigated to improve the tensile strength of concrete. According to the established design standards such as Eurocode 2 (European Union [EU], 2004) and ACI 318-14 (American Concrete Institute [ACI], 2014), the tensile strength of concrete depends on a variety of factors, including the concrete grade, curing conditions, age of concrete, and structural member dimensions. The utilization of fiber reinforcements is an interesting approach for its capability to improve the tensile strength of concrete and enhance its overall toughness and durability (Banthia & Sappakittipakorn, 2007).

The utilization of fiber reinforcements in concrete requires a careful selection of the fiber type, which includes steel, glass, polypropylene, or natural, each offering particular characteristics and limitations, which the specific demands of the concrete framework should guide (Bentur & Mindess, 2007). Incorporating steel fibers into concrete has increased its tensile strength and toughness substantially. However, it should be noted that steel fibers are susceptible to corrosion when exposed to harsh environmental conditions (ACI, 2002b; Nanni, 2003). Glass fibers, on the other hand, improve tensile and flexural strength but require alkali-resistant treatments to stop degradation in the high pH environment of concrete (Lau & Anson, 2006; Provis, Palomo & Shi, 2015). Polypropylene (PP) fibers, although having a lower tensile strength than steel or glass, provide outstanding impact resistance and shrinkage control and show impressive resistance to corrosion and chemical stability (ACI, 2002b; Banthia & Sappakittipakorn, 2007; Bentur & Mindess, 2007). Natural fibers, such as sisal, jute, and coir, contribute a certain degree of tensile strength enhancement and crack resistance to a material. However, they require particular treatments to improve their durability in wet environments (Sudin & Swamy, 2006).

Research investigations examining the influence of fiber content on the characteristics of concrete have produced a range of interesting findings throughout the years. In a study by Choi and Yuan (2005), the researchers investigated the effects of incorporating glass and PP fibers into concrete. Their findings contradicted the anticipated relationship between fiber content and strength, suggesting that an increase in strength corresponds to a higher fiber volume of less than 1% (Choi & Yuan, 2005). Similarly, Hasan, Afroz and Mahmud (2011) conducted an experiment investigating various volume ratios of PP fibers. They observed that the compressive strength of concrete reached its maximum value at a 0.51% volume ratio. Varghese and Fathima (2014) investigated the incorporation of crimped steel fibers, hooked--end steel fibers, and PP fibers into their concrete compositions. A PP fiber volume ratio of 0.5% was determined to yield the highest levels of compressive and flexural strength. Li, Niu, Wan, Liu and Jin (2017) conducted a subsequent study to examine a broader range of volume ratios between glass and PP fibers. The researchers determined that a 0.9% volume ratio marked the critical point at which both compressive and flexural strength started to decline. Similarly, the study by Lee, Cho, Choi and Kim (2016) revealed a reduction in flexural strength as the volume of fibers surpassed 0.5%. In agreement with prior research, the recent study conducted by Al Enezi, Al-Arbeed, Alzuwayed, Al-Zufairi and Awad (2023) confirmed that a 0.65% fiber volume ratio is associated with the highest compressive strength.

This research focuses on the enhancement of the tensile performance of concrete by incorporating synthetic PP fibers at proportions of 0.5% and 1.0% by volume, compared to conventional non-fiber reinforced concrete. The concrete mix is specified to have a compressive strength of 40 MPa, and Type 3 portland cement – famous for its early strength qualities – is chosen as the composition's binder. The research follows the ASTM C39/C39M standard (American Society for Testing and Materials [ASTM], 2003b) for evaluating the produced concrete compressive strength to guarantee consistency and reliability. The performance of the PP fiber-reinforced concrete is evaluated using standardized testing procedures according to the ASTM C1609C/1609M (ASTM, 2019). This test provides a comprehensive examination of the flexural behavior of PP fiber-reinforced concrete (PPFRC). Key performance indicators, such as the modulus of rupture, residual strengths, and toughness indices, are evaluated in detail. Following a thorough analysis of the impact of fiber content on essential performance parameters, it becomes evident that PP fiber reinforcement enhances the tensile strength and overall performance of the concrete.

Materials and concrete mixed design

The present investigation involved formulating a concrete mixture to attain a compressive strength of 40 MPa. According to the ACI 211.1-91 standard (ACI, 2002), the proportion of superplasticizers was appropriately modified to achieve a slump value greater than 10 cm, thereby ensuring uniformity in the amounts of cement, gravel, and sand. The mix proportions for each variation of fiber content utilized in this study are presented in Table 1, providing a comprehensive overview. This research utilized a PP fiber with a remarkable tensile strength of 550 MPa. The fiber's physical characteristics consisted of a diameter measuring 0.71 mm and a length of 48 mm. Table 2 provides an extensive description of the geometry and material properties of the PP fiber.

TABLE 1. Mix proportion of concrete

Synthetic macrofiber [kg·m^{-3}]	Fiber volume fraction [%]	Cement [kg·m^{-3}]	Coarse aggregate [kg·m^{-3}]	Fine aggregate [kg·m^{-3}]	Water [kg·m^{-3}]	Superplasticizer [l·m^{-3}]
0.0	0.0	415	1029	810	114	4.15
4.5	0.5	415	1029	810	114	4.25
9.0	1.0	415	1029	810	114	4.50

Source: own work.

TABLE 2. Geometric and material properties of polypropylene fiber

Type	Specific gravity [-]	Equivalent diameter [mm]	Length [mm]	Tensile strength [MPa]	Modulus of elasticity [GPa]	Melting point [°C]
Macrofiber	0.92	0.71	48	550	6.9	170

Source: own work.

Furthermore, Figure 1 provides a visual representation of the fiber, enabling a better understanding of its physical appearance.

Type 3 portland cement, also known as rapid hardening portland cement, was used for the experiment. This type of cement is characterized by a significant amount of C_3S, which results in a significant exothermic reaction during the hydration process. It also exhibits a higher degree of fineness than Type 1 portland cement. Consequently, this cement type has gained widespread recognition for its exceptional early strength characteristics.

The process of choosing fine and coarse aggregates was conducted with careful attention to adherence to the ASTM C 33 standard (ASTM, 2003a). The specifications mentioned above were carefully selected to uphold experimental consistency and precision. The natural fineness modulus of the fine aggregate was 2.60, and its specific gravity was 2.65. The coarse aggregate, having a maximum particle size of 20 mm, demonstrated a fineness modulus of 3.4 and a specific gravity of 2.7.

FIGURE 1. Configuration of the polypropylene fiber
Source: own work.

The concrete mixture was improved by utilizing Type F superplasticizer, which is recognized as a high-range admixture that reduces water and increases slump. The superplasticizer was compatible with the standards outlined in ASTM C494/C494M standard (ASTM, 2013). Incorporating the substance resulted in significant improvements in the concrete mixture slump, while the water and cement proportions remained constant. This led to improved workability and compatibility of the various components of the mixture.

To ensure uniform distribution, the mixing process started with dry sand, gravel, cement, and PP fiber mix. After that, water infused with the superplasticizer was added, and the mixing process was sustained until the targeted slump value was achieved. The ultimate concrete mixture was carefully deposited into steel molds with measurements of 150 × 150 × 150 mm for the compression examination and 150 × 150 × 500 mm for the flexural examination.

Test methods and performance parameters

This research aims to investigate the influence of different fiber content (0.0%, 0.5% and 1.0% by volume) on the compressive and flexural strengths of concrete. The experiments involved the results of compressive strength assessments on 15 × 15 × 15 cm^3 cubic specimens, and a comparative analysis was carried out between the effects of fiber inclusion and ordinary concrete at the age of 1 day, 7 days, and 28 days, according to the ASTM C39/C39M standard. Beam specimens with the dimensions of 15 × 15 × 50 cm^3 were subjected to flexural strength tests at 28 days following the ASTM C 1609/C1609M standard (ASTM, 2019).

The compression test employed cube-shaped concrete specimens with the dimensions of 15 × 15 × 15 cm^3. Using a universal testing machine, the loading rate was controlled with 0.15 $MPa \cdot s^{-1}$, according to the guidelines specified in ASTM C39/ /C39M standard (ASTM, 2003b). This experimental study involved the collection of three distinct sets of specimens. The first group comprised conventional concrete specimens, which functioned as the benchmark for comparative analysis. The other two groups consisted of corresponding concrete specimens containing 0.5% and 1.0% fiber content per unit volume. Each group consisted of three specimens. The concrete specimens were tested at different ages, specifically 1 day, 7 days, and 28 days. Following the achievement of the tests, the highest amount of force applied during the compression process was recorded and subsequently used to calculate the compressive strength via the application of Equation 1.

$$f = \frac{P}{A}, \tag{1}$$

where: f – compressive strength [MPa], P – load [N], A – area [mm^2].

The flexural strength of concrete was investigated by conducting tests on specimens with the dimensions of 15 × 15 × 50 cm when a concrete age of 28 days. The specimens were placed on a simple support, with the upper surface of the concrete facing sideways during the testing process, according to its position at the casting specimens. The support points were spaced at a distance of 45 cm from each other. The experiment was conducted following the ASTM C 1609C/1609M standard, utilizing a four-point loading method. The load was applied at a distance of one-third of the beam length from both ends, specifically at a point 15 cm away from the end. This generated a pure bending moment at the center region of the beam. The load application rate was controlled at 0.1 mm·min^{-1} and experienced until the specimen underwent deformation to a magnitude of 3 mm or L/150. The test specimens' displacement was measured using two linear variable differential transducers (LVDTs) located at the applied force point on both sides of the beam, as depicted in Figure 2.

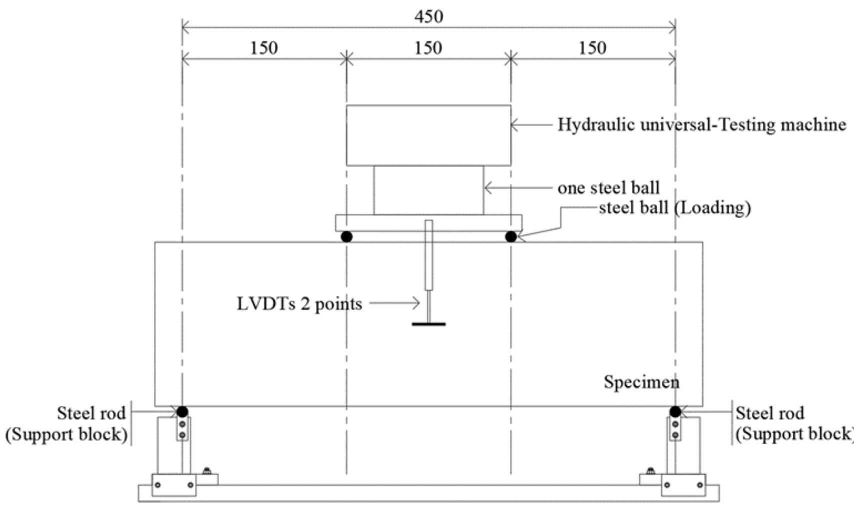

FIGURE 2. Specimen test setup for the flexural test according to ASTM C 1609/1609M standard
Source: own work.

The maximum resistance can be used to determine the initial peak strength or the modulus of rupture using Equation 2.

$$f = \frac{PL}{bd^2}, \tag{2}$$

where: f – strength [MPa], P – load [N], L – span length of beam [mm], b – width of beam [mm], d – depth of beam [mm].

The residual strength at the deformation of L/600 and L/150 also employed Equation 2. The toughness value can also be determined by calculating the area under of load-deformation curve from the starting point to the deformation point equivalent to L/150.

Results and discussion

Compressive strength test

The compressive strength tests carried out according to the ASTM C39/C39M standard provided insights into the strength variations between plain concrete and PPFRC at distinct ages of 1 day, 7 days, and 28 days. The average compressive strength values for each of these concrete mixes are illustrated in Table 3 for a more straightforward comparison. The test results indicate a general trend of increasing compressive strength over the curing period for all mixes. The concrete with PP fiber 0.5% by volume consistently demonstrated the highest average compressive strength at all testing times, reaching 31.07 MPa, 41.51 MPa, and 46.68 MPa at 1 day, 7 days, and 28 days, respectively. This performance indicated an optimal fiber volume of 0.5% for maximizing compressive strength. Even though the concrete mixed with a higher fiber volume of 1.0% consistently exhibited lower average compressive strengths, these values became within the same range as those of plain concrete, demonstrating the fibers' impact on the mix's strength properties. The compressive strengths of concrete with PP fiber 1.0% by volume were reported to be 28.48 MPa, 37.13 MPa, and 42.96 MPa at 1 day, 7 days, and 28 days, respectively. These values were similar to the compressive strengths of plain concrete, which were recorded as 29.05 MPa, 37.50 MPa, and 42.25 MPa at their respective time periods. Therefore, the optimal proportion of PP fiber for achieving maximum compressive strength in the concrete mixture is 0.5% by volume.

The relationship between different volume ratios of compressive strength in fiber-reinforced concrete and non-fiber-reinforced concrete with the various proportions of PP fiber is depicted in Figure 3. This information was derived from previous studies (Choi & Yuan, 2005; Hasan et al., 2011; Varghese & Fathima, 2014; Li et al., 2017; Al Enezi et al., 2023) that utilized type PP macrofibers, which was consistent with the approach employed in this current study. The incorporation of fibers in concrete at volume percentages ranging from 0.3–0.8% increased its compressive strength.

TABLE 3. Compressive strength test result

Fiber volume fractions [%]	Compression strength [MPa]								
	one-day old sample			seven-day old sample			28-day old sample		
0.0	29.36	avg	29.05	36.44	avg	37.50	40.54	avg	42.25
	27.48			37.30			42.67		
	30.30			38.75			43.53		
0.5	31.92	avg	31.07	41.91	avg	41.51	46.43	avg	46.68
	30.13			41.48			45.66		
	31.15			41.14			47.97		
1.0	28.08	avg	28.48	37.13	avg	37.13	42.67	avg	42.96
	28.59			36.70			43.10		
	28.76			37.55			43.10		

Source: own work.

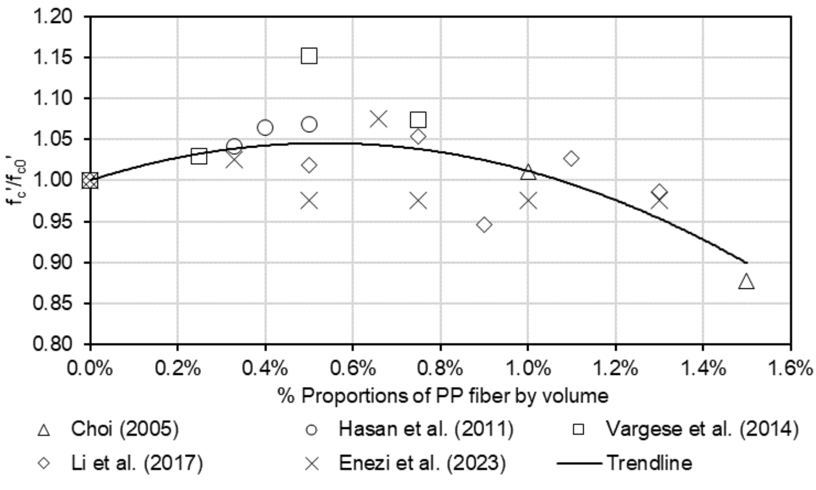

FIGURE 3. The relationship of the ratios of compressive strength in fiber-reinforced concrete and non-fiber-reinforced concrete with the proportion of polypropene fiber from previous studies

Source: own work based on Choi and Yuan (2005), Hasan et al. (2011), Varghese and Fathima (2014), Li et al. (2017), Al Enezi et al. (2023).

Nevertheless, it can be observed that the compressive strength declines as the fiber-mix ratio increases, which agrees with the results obtained in the present investigation. Based on the observed pattern in the correlation between various volume ratios of compressive strength in fiber-reinforced concrete and non-fiber-reinforced concrete, a mathematical expression in the form of a second-order polynomial equation, shown as Equation 3, was derived.

$$\frac{f_c'}{f_{c0}'} = -1{,}577.712x^2 + 16.929x + 1.000. \tag{3}$$

In this experiment, when incorporating fiber mix volume percentages of 0.5% and 1.0% into the equation, the resulting compressive strengths were measured to be 44.16 MPa and 42.74 MPa, respectively. In comparison to the empirical findings, it was observed that the mean compressive strength measurements for concrete specimens incorporating fiber volumes of 0.5% and 1.0% are 46.68 MPa and 42.96 MPa, correspondingly, with the differing percentages of 5.71% and 0.52%, respectively.

Flexural strength test

Concrete beam specimens were tested following the ASTM C 1609C/1609M standard to determine the flexural strength of concrete. Figure 4 illustrates the relationship of force and deformation for plain concrete and concrete with PP fiber 0.5% and 1.0% by volume. The maximum flexural strength of the three different test components had been determined from the force-deformation relationship as similar. The concrete with PP fiber 0.5% by volume has the maximum flexural strength, followed by the concrete with PP fiber 1.0% by volume and the plain concrete sample with the lowest flexural strength. The resulting pattern corresponds to the values of the compressive strength. The modulus of rupture or flexural strength can be determined using the formula for bending stress occurring at the bottom surface of the test specimen cross section at the middle of the beam, as shown in Equation 2. Table 4 presents the calculated flexural strengths of each test specimen. Fiber-reinforced concrete specimens had first peak strengths greater than plain concrete specimens. The concrete with PP fiber 0.5% by volume has the highest value, with an average modulus of rupture of 4.40 MPa. The concrete mixed with PP fiber 1.0% by volume shows a lower modulus of rupture than PP fiber content 0.5% by volume, with an average of 4.27 MPa. The modulus of rupture of plain concrete is the lowest, averaging 3.98 MPa. Notably, the fiber volume in the concrete mix had no immediate effect on the modulus of rupture (Patel, Desai & Desai, 2012; Dopko, Najimi, Shafei & Wang, 2018). According to ACI 318M-11 standard (ACI, 2011), the relationship between the beam samples' compressive strength and bending strength may be used to compute the modulus of rupture of concrete, as shown in Equation 4. The calculated modulus of rupture for plain concrete with a design compressive strength of 40 MPa is 3.92 MPa. Conversely, it was found that the experimental findings were 3.98 MPa, demonstrating a strong correlation between the two values.

$$f_r = 0.62\sqrt{f_c'}. \tag{4}$$

Regarding the behavior expressed after reaching the peak flexural strength, it can be observed that the plain concrete's resistance experiences a rapid decline, ultimately resulting in negligible residual strength, as depicted in Figure 4a. The concrete with PP fiber 0.5% by volume exhibits a residual strength of approximately 7,500 N, as shown in Figure 4b, despite experiencing a rapid decline. Moreover, the specimen composed of concrete with PP fiber 1.0% by volume displays the greatest residual strength, approximately 10,000 N, as illustrated in Figure 4c. The strength reduction following the cracks' development depends on the volume of fibers present, whereby a greater fiber volume corresponds to a lower decrease in residual strength. As the deformation state increases, cracks expand while the resistance force remains relatively constant. The softening behavior of strength is observed in PPFRC after the development of cracks. The post-crack behavior of the test samples shows to be independent of the compressive strength.

According to the ASTM C 1609C/1609M standard, the residual strength of concrete, which is calculated after cracking, refers to the material's capacity to endure stress and maintain its structural integrity after damage. The indicators above were compared to the first peak. Two critical values considered were $f^D{}_{600}$, which signifies the remaining strength after a deformation of L/600, and $f^D{}_{150}$, which represents the strength after a deformation of L/150. The data presented in Table 4 shows that the $f^D{}_{600}$ values for pain concrete and concrete with PP fiber 0.5% and 1.0% by volume are 0.36 MPa, 1.04 MPa, and 1.61 MPa, respectively. When compared to the first peak strength of each type of concrete, these values represent 9.04%, 23.70%, and 37.73%, respectively. The results indicate an interesting improvement in residual strength with PP fiber, as evidenced by the $f^D{}_{600}$ values of concrete with PP fiber 0.5% and 1.0% by volume, which are 2.9 and 4.5 times higher than those of pain concrete. The pain concrete exhibited a negligible $f^D{}_{150}$ value, demonstrating that it cannot sustain residual strength following substantial deformation. In contrast, it had been observed that concrete with PP fiber 0.5% and 1.0% by volume demonstrates $f^D{}_{150}$ values of 0.74 MPa and 1.16 MPa, respectively. Compared to the first peak strength, these performances accounted for 16.74% and 27.23%, respectively. Therefore, it can be inferred that an increase in the amount of fiber results in a proportional improvement of the residual strength of the concrete. This enhancement in strength is attributed to the fibers, which bridge the cracks in the concrete, resulting in improved tensile strength and resistance to crack propagation due to the widespread distribution of fibers throughout the cross-section of the concrete.

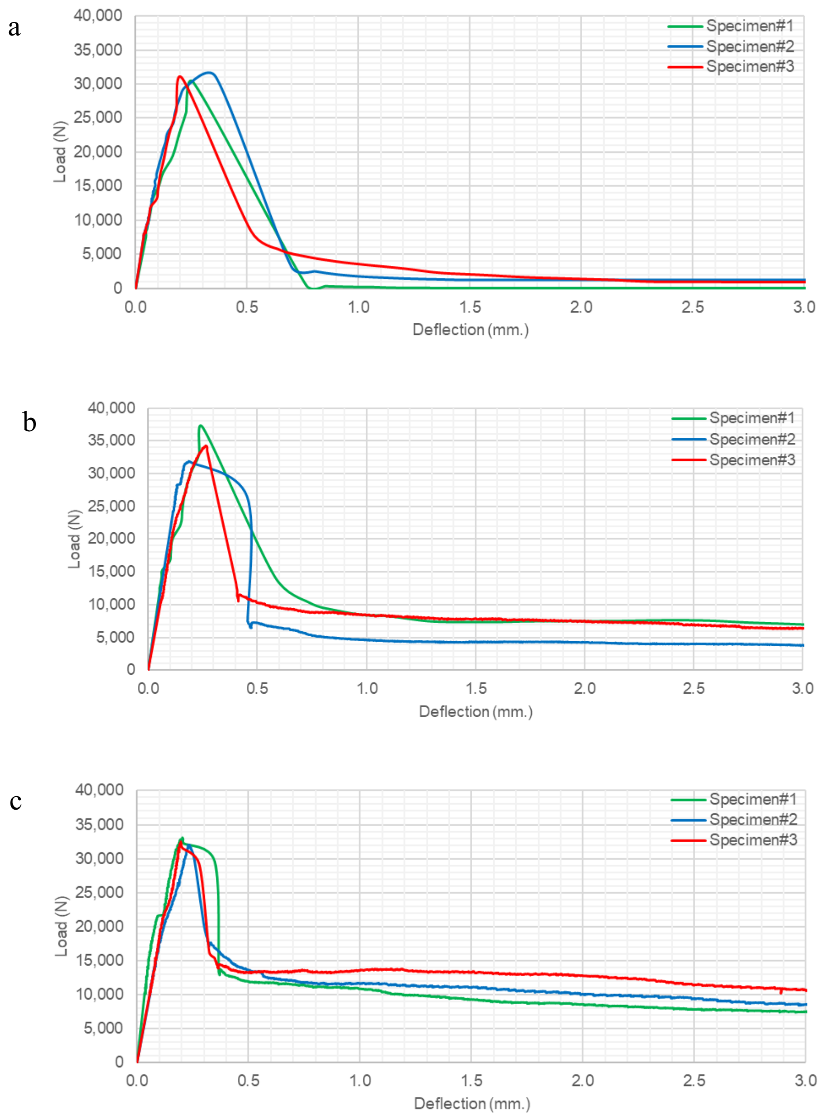

FIGURE 4. The load-deflection curves obtained from the flexural tests conducted on the specimens exhibit variations in fiber content: a – 0.0% by volume; b – 0.5% by volume; c –1.0% by volume

Source: own work.

Toughness is noteworthy when analyzing the test results according to the ASTM C 1609C/1609M standard. It serves as an essential measure of performance for fiber post-cracking. The toughness principle relates to a material's capacity to withstand crack propagation or absorb energy when subjected to flexural load. Consistent with the hypothesis proposed in this research, the addition of fibers into concrete has the potential to improve its tensile strength, which leads to a more ductile behavior in the structures. The determination of toughness can be achieved by calculating the integral of the force-deformation curve from the initial point up to the point where the deflection reaches L/150. The experimental results indicated that the toughness measurements of pain concrete and concrete with PP fiber, 0.5% and 1.0% by volume, were 13.98 J, 28.19 J, and 36.63 J, respectively. The findings suggest that adding PP fiber in concrete at volume proportions of 0.5% and 1.0% results in a significantly improved toughness, with values approximately twice and 2.6 times higher than those observed in pain concrete. Therefore, it can be inferred that an increase in fiber content leads to an increase in toughness, contributing to a more ductile structure. Consequently, this enhancement allows the concrete to withstand greater tensile forces, underscoring the value of fiber reinforcement in concrete mixtures.

TABLE 4. Flexural strength test results

Fiber volume fraction [%]	Modulus of rupture [MPa]			f^{D}_{600} [MPa]			f^{D}_{150} [MPa]			Toughnes [J]		
0.0	3.82	avg	3.98	0.05	avg	0.36	0.00	avg	0.00	12.10	avg	13.98
	4.08			0.42			0.00			15.35		
	4.04			0.61			0.00			14.49		
0.5	4.59	avg	4.40	1.28	avg	1.04	0.88	avg	0.74	32.55	avg	28.19
	4.18			0.70			0.50			22.82		
	4.43			1.14			0.83			29.20		
1.0	4.32	avg	4.27	1.49	avg	1.61	0.98	avg	1.16	33.68	avg	36.63
	4.27			1.58			1.14			35.36		
	4.22			1.76			1.37			40.86		

Source: own work.

Figure 5 illustrates the correlation between various volume ratios of the modulus of rupture of fiber-reinforced concrete and the modulus of rupture of non-fiber-reinforced concrete, as evidenced by previous studies (Varghese & Fathima, 2014; Li et al., 2017; Al Enezi et al., 2023). The addition of fibers to concrete in volume percentages ranging from 0.1–0.8% had been found to increase the modulus of rupture value, which agreed well with the obtained results.

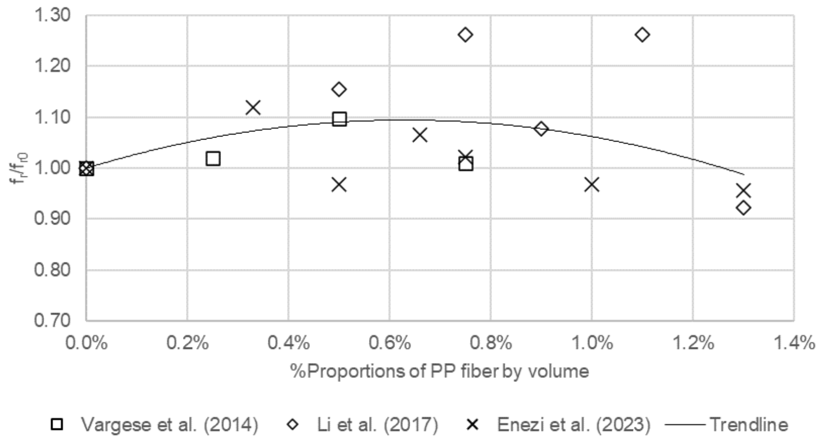

FIGURE 5. The relationship of the ratios of modulus of rupture in fiber-reinforced concrete and non-fiber-reinforced concrete with the proportion of polypropene fiber from previous studies

Source: own work based on Varghese and Fathima (2014), Li et al. (2017), Al Enezi et al. (2023).

As depicted in Equation 5, the second-order polynomial relationship was derived from the trendline representing the correlation between various volume ratios of modulus of rupture in fiber-reinforced concrete and non-fiber-reinforced concrete.

$$\frac{f_r}{f_{r0}} = -2{,}372.848x^2 + 29.892x + 1.000. \tag{5}$$

When applying the fiber mix volume percentages of 0.5% and 1.0% obtained from this study to Equation 5, the modulus of rupture was determined to be 4.34 MPa and 4.23 MPa, respectively. The results were consistent with the modulus of rupture values derived from the experimental data. The average MOR of concrete mixed with fiber volumes of 0.5% and 1.0% are 4.40 MPa and 4.27 MPa, respectively. The deviation values for these measurements are 1.41% and 1.06%, respectively.

Distribution of polypropylene fibers

The uniform dispersion of fibers can be observed on the fractured surface of the specimens, as depicted in Figure 6, following their failure. This particular result can be explained by meticulous preparation during the mixing process of the concrete components, in which the fibers were distributed uniformly before adding water. The concrete mixture effectiveness was enhanced by adding superplasticizers, which facilitated suitable workability and effective casting. Examining the fiber distribution at the fracture surface indicates that most fibers remained undamaged, while only a minor fraction experienced rupture. The primary failure mechanism exhibited by the fibers was 'pull-out', which is explained by insufficient bonding between the concrete and fibers.

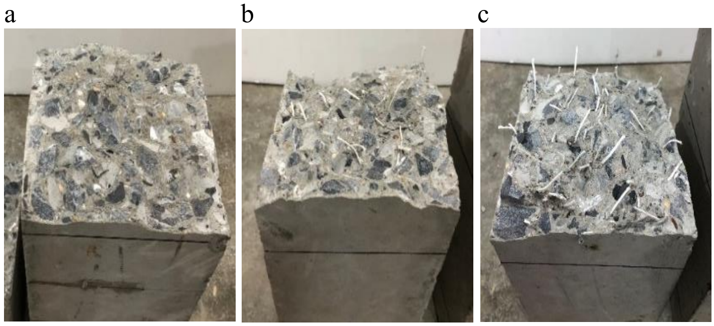

FIGURE 6. Fracture faces of the polypropene fiber-reinforced concrete beam: a – plain concrete, b – polypropylene fiber 0.5% by volume; c – polypropylene fiber 1.0% by volume

Source: own work.

Consequently, using fibers with a rough texture or increasing the fiber length could improve the interfacial adhesion potency between the fiber and the concrete matrix, thereby eliminating the probability of the pull-out collapse. The utilization of crimped-shaped fibers (Oh, Kim & Choi, 2007) and longer fibers (Singh, Shukla & Brown, 2004) presents the possibility of improving the mechanical properties and durability of fiber-reinforced concrete. The present study highlights the significant influence of fiber dispersion and bond strength on the improvement of post-cracking behavior and overall performance of fiber-reinforced concrete.

Conclusions

The present investigation systematically evaluated the mechanical characteristics of plain concrete and PPFRC. The study included experimental testing utilizing ASTM C39/C39M to evaluate compressive strength and ASTM C 1609C/1609M for assessing flexural performance. The findings of the research can be summarized as follows:

– The concrete with PP fiber 0.5% by volume exhibited consistently high performance, as demonstrated by compressive strength tests conducted following ASTM C39/C39M standard. The mixture based on investigation showed the greatest mean compressive strength across all testing ages, with values of 31.07 MPa, 41.51 MPa, and 46.68 MPa recorded at 1 day, 7 days, and 28 days, respectively.

The mechanical properties indicated by the above values exhibited superior performance compared to plain concrete and concrete with PP fiber 1.0% by volume. Thus, it had been identified that a fiber volume portion of 0.5% represents the most advantageous amount for enhancing the compressive strength of concrete.

– The analysis of the behavior of concrete after cracking demonstrated essential improvements in residual strength and toughness with the addition of PP fibers. The concrete with PP fiber 0.5% and 1.0% by volume resulted in significant enhancements in the f^D_{600} values, which indicate the residual strength of the material after the deformation of L/600. The concrete with PP fiber 0.5% and 1.0% by volume exhibited a f^D_{600} value of 1.04 MPa and 1.61 MPa, respectively. These values represented significant improvements over the 0.36 MPa f^D_{600} value observed in the plain concrete. Furthermore, the addition of PP fiber into concrete at volumes of 0.5% and 1.0% yielded toughness measurements that were 2.0 (28.19 J) and 2.6 times (36.63 J) greater than the value of 13.98 J for plain concrete. The observation above emphasized the critical advantage of adding fiber reinforcement in enhancing the ability of concrete to withstand crack propagation and absorb energy when subjected to flexural load.
– The evaluation of the fractured surfaces of the specimens demonstrated that the realization of these performance improvements depended on the uniform distribution of fibers and the development of adequate bonding with the concrete. The addition of fibers in the concrete matrix resulted in an essential improvement in its overall performance. The predominant failure mode was 'pull-out' indicating inadequate bonding between the concrete and fibers. This illustrates the potential of enhancing the mechanical properties of fiber-reinforced concrete by improving the bonding between the fiber and concrete matrix. The approach above could involve the utilization of longer or rough fibers, which denotes a suitable option for future research.

Acknowledgements

The authors gratefully acknowledge the funding supported by Research and Graduate Studies Sustainable Infrastructure Research and Development Center, Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen 40002, Thailand and the Provincial Electricity Authority (PEA).

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Summary

Enhancement of tensile performance of concrete by using synthetic polypropylene fibers. The research attempted to investigate the effect of polypropylene fibers (PP fibers) on the mechanical characteristics of concrete. According to ASTM C39/C39M and ASTM C 1609/C1609M, standard testing methods were used to examine the concrete compressive and flexural strength, post-cracking behavior, and toughness. The mechanical properties were evaluated at different ages of concrete curing, namely 1 day, 7 days, and 28 days, and for different quantities of fiber volume portions, specifically 0.0%, 0.5%, and 1.0%. The results demonstrate that a fiber volume of 0.5% is the most effective in obtaining the highest compressive strength. The recorded values at the related testing ages

were 31.07 MPa, 41.51 MPa, and 46.68 MPa. Additionally, the utilization of 0.5% and 1.0% volume of PP fiber in concrete resulted in improved flexural strength and post-cracking performance. The toughness values for these mixes were 2.0 and 2.6 times higher than those for the plain concrete. Upon analyzing the fracture surface, there was a homogeneous distribution of fibers, which played a significant role in enhancing the overall functionality of the concrete. The research validated that the inclusion of polypropylene fibers substantially enhanced the mechanical characteristics of concrete, emphasizing the potential of fiber reinforcement in concrete-based implementations.