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The Characteristics of Polymer Concrete Reinforced with Polypropylene Fibres Under Axial and Lateral Compression Loads

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ABSTRACT

The use of cement is expected to increase over the years as the infrastructure continues to develop, and the needs to repair or rehabilitate an old and deteriorated building are necessary. However, many investigations have been conducted to establish promising polymer concrete applications in the last few decades. Meanwhile, using concrete in the construction industry has led to environmental issues. It is because relying on cement production in concrete will contribute to about 7% of the world's carbon dioxide emissions. Therefore, polymer concrete was introduced in this study to minimise the use of cement in the industry. This research investigated the influence of different amounts of polypropylene (PP) fibre content on polymer concrete (PC) properties by determining the compressive strength, flexural strength and indirect tensile strength. Furthermore, the results of PC failure characteristics have been discussed. The polymer concrete specimens in this study have been cast into cylinders and prismatic specimens using PVC pipe and plywood formwork to determine the compressive strength, splitting tensile strength and flexural strength. By reinforcing PP fibre in the polymer concrete with a specific percentage of fibre reinforced, the overall strength of the polymer concrete

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was improved. Based on the compressive, splitting tensile, and flexural test results, it has been hypothesised that the 0.16% PP fibre will considerably improve polymer concrete. Additionally, PP fibre maintains a moisture content of less than 0.5% in the aggregates, resulting in a significant enhancement in the mechanical properties of polymer concrete.

Keywords: Axial and lateral, compression load, material characteristics, polymer concrete, polypropylene fibre

INTRODUCTION

The global population has increased to over 6.3 billion. More than 60% of the world's population will reside in cities by 2030. Population rise is a significant factor in housing demand. Concrete is commonly used in the premises construction field (Liu et al., 2020; Manjunatha et al., 2021). Roads, bridges, buildings, energy, and water management systems all require a great deal of concrete, making it the second most commonly used material worldwide each year after water. The previous 20 years have produced over half of the concrete used throughout history. The global concrete industry roughly consumes 7.5 billion tonnes annually (Arulmoly et al., 2021; Sanjith et al., 2015; Scope et al., 2021). The prime ingredient for making concrete is, of course, cement. However, cement clinker production is a very energy-intensive and polluting process. Figure 1 displays the cement industry's increasing rate of CO_2 emissions and its proportion of total annual emissions (Ghasemi, 2019; Harison et al., 2014; Oey et al., 2017; Teixeira et al., 2022).

In order to reduce the product's carbon footprint and overall cost, it is common to practise using as little cement as possible when proportioning cementitious mixtures. As a result, the methods and actions that reduce the carbon footprint of cement are of extreme relevance to the concrete and cement industries. Over the past century, since the widespread use of coal for power generation began in the 1920s, millions of tonnes of ash and other by-products have been produced. About 500 million tons, or 75 to 80% of the total ash generated, is fly ash. The annual global production of coal ash is estimated at roughly 600 million tons, and the disposal of a large amount of fly ash has become a serious environmental problem. Therefore, in recent years, the use of fly ash as an ordinary Portland cement replacement in concrete mixes has become common. These pozzolanic materials, such as fly ash, can contribute to forming calcium silicate hydrates by reacting with the calcium hydroxide produced during cement hydration, thus having comparable properties to Portland cement. Their use can be a promising way to address concrete sustainability (Abdulrahman et al., 2022; Blazy & Blazy, 2021; McCarthy et al., 2022; Mocharla et al., 2022; Qin et al., 2019).

Concrete is a highly compressive material but around ten times smaller tensile strength. It exhibits brittle behaviour and does not permit stress transfer following cracking. Polypropylene Fibres (PPF) can be added to the concrete mixture to reduce the possibility of brittle failure and enhance the material's mechanical properties to overcome this problem. Polypropylene fibre (PPF) is one of the most widely used fibres in industrial or daily life. Polypropylene-fibre-reinforced concrete (PPFRC) has been common recently in different applications such as tunnels, ground slab bridge decks, canals, concrete pipe, and pavement construction, which shows a noticeable improvement in mechanical characteristics such as tensile strength, flexural strength, toughness, and energy absorption (Afroughsabet & Ozbakkaloglu, 2015; Akid et al., 2021; Asyraf et al., 2022; Blazy, 2021; Jafari et al., 2018; Supian et al., 2022).

Polymer concrete (PC) is a type of FRC that is strong enough to be used in precast applications. Thus, it is important because the strength will permit the structures to resist higher stresses early due to form-stripping, handling, transportation, and erection operations. Polymer concrete is a form of concrete in which a polymer is used as a binder instead of lime-type cement. The overall performance of polymer concrete depends on the amount and specific types of resin used in the composite material (Mohamad et al., 2019; Ribeiro et al., 2004). Furthermore, the properties of concrete with varying fibre concentrations have been studied in various parameters. Polypropylene fibres have been used in construction because of their availability, high strain, increased cracking resistance, low cost, and superior softening response. Meanwhile, the fly ash-polypropylene-fibre concrete mixture has been used in industrial and civil construction sprayed concrete, tunnels, guard rails, anti-seepage concrete structures, anti-cracking, and waterproof layers. Thus, in the context of the study of the mechanical strength capabilities of polymer concrete, the incorporation of polypropylene fibre and other synthetic fibre content substantially enhanced the tensile and compressive capacity of concrete (Afroughsabet & Ozbakkaloglu, 2015; Agusril et al., 2012; Blazy, 2021; Yin, 2015; Pan et al., 2021; Ramezanianpour et al., 2013).

Researchers are interested in concrete durability due to the long lifespan of the structure. Therefore, the properties of polymer concrete can be affected by many factors for diverse applications. For instance, Supplementary Cementitious Materials (SCM) from other materials can lower the cost of cement while resolving landfill waste disposal. Meanwhile, the study by Akid et al. (2021) has indicated that adding supplementary cementitious materials from the fibres to concrete has been proven to improve the concrete's toughness and toughened qualities of crack propagation characteristics and post-softening residual stress in compression. Besides, Reis's (Fluminense, 2014) experiments have shown that glass fibres and nylon have improved the mechanical characteristics of reinforced polymer concrete. Meanwhile, in the study by Rebeiz (1996) of steel fibres in polymer concrete, it was identified that adding 1.3% of fibre content by volume increases the compressive strength of polymer concrete.

Furthermore, several studies have shown that the mechanical strength of polymer concrete is 4 to 5 times that of cement concrete (Hameed & Hamza, 2019). Likewise, Kayali et al. (2003) and Song et al. (2005) have stated that polypropylene fibres contribute to the strength of compression, flexure, pressure, under-impact blows, and plastic shrinkage. Furthermore, the advantages of polymer concrete compared to ordinary Portland concrete make PC widely used in many applications, especially in the construction and repair of structures due to the rapid hardening of PC, ability to withstand corrosive elements, higher compressive strength, lower permeability, and many more (Kayali et al., 2003; Song et al., 2005). Polymer waste polypropylene from bottle caps was used in a study by Martínez-López et al. (2021) to enhance compressive strength, compressive deformation, and flexural deflection by 82%. However, recent advancements in polymer concrete have resulted in considerable reductions in the cost of construction materials, indicating that polymer concrete is progressively becoming more common. In addition, because of their physico-chemical characteristics and being inexpensive, they have become an environmental concern due to inadequate ultimate disposal methods (Bedi et al., 2021; Ferdous et al., 2020; Ghasemi, 2019)

The curing conditions influence the ultimate qualities of polymer concrete. Researchers discovered that polymer concrete might be cured in various methods, including at room or high temperatures, underwater, with saline solutions, and more (Guo et al., 2021; Rebeiz, 1995). Allowing the specimens to cure at room temperature is one of the most preferred methods of curing polymer concrete since it is simple to handle and operate. Polymer concrete may obtain a strength of roughly 70% to 75% after one day of curing at room temperature, but typical Portland cement concrete can only achieve a 20% strength growth of its 28-day strength in one day due to its fast-curing characteristic. Although higher temperature curing speeds up the curing of polymer concrete, most research agrees that the optimum curing period for polymer concrete is 7 days since the compressive strength of PC is reported to become consistent after 7 days of curing (Ferdous et al., 2020; Ohama & Demura, 1982). Hsie et al. (2008) found that adding polypropylene hybrid fibre to concrete yielded more strength than using only one fibre. With the addition of hybrid polypropylene fibre, the compressive strength increased by 14.60% to 17.31%, the splitting tensile increased by 8.88 to 13.35 %, and the modulus of rupture increased by 8.99% to 24.60%

The research demonstrated that using polypropylene fibre-reinforced concrete in public areas is viable. The concrete polymer might help greatly for usage in vandalism, surface abrasion, and improved impact damage characteristics since they are subjected to, for example, unfavourable weather conditions. Therefore, this research investigated the effect of polypropylene fibre PPF on the mechanical properties of polymer concrete when in different percentages as reinforcement through compressive strength, indirect split tensile strength, and flexural strength. Polypropylene is added to polymer concrete at 0%, 0.12%, 0.16%, and 0.2% in mixes 1, 2, 3, and 4.

METHODOLOGY

Coarse Aggregates

Aggregates account for 60% to 75% of the total volume of concrete. Coarse aggregates significantly affect polymer concrete's bending and compressive strength. Therefore, the aggregates must be free from dust and undesired contaminants to avoid any interaction with the setting and hardening of resin in polymer concrete. The aggregates used in polymer concrete are often determined by the availability of resources, with the ideal design composition being 50% pebble, 42.5% sand, and 7.5% resin. As a result, the cost of creating composites will be reduced. Crushed coarse limestone aggregates were used to produce polymer concrete. The 5 mm single size was used to ensure that the resin is disseminated and coated uniformly with the aggregate while maintaining the same flow ability; it is possible to utilise less polymer matrix when using smaller aggregates as opposed to larger aggregates with a large surface area.

Furthermore, when single-sized aggregates are employed, the resin and filler used may readily cover the gaps or space between the stones. Aggregates with an angular form and a rough surface roughness were particularly crucial in this study because a stronger bond could be created when the aggregates were combined with the resin, providing the polymer concrete with more strength. Angular aggregates with a rough surface roughness were also important because when they were mixed with the resin, a stronger bond could be formed, providing the polymer concrete more strength.

Fly Ash

Fly ash (FA) is the finely divided residue that results from pulverised coal combustion and is transported from the combustion chamber by exhaust gases. The particle size distribution of CFA is similar to the particle size of cement, with an average diameter of 9 μm. Therefore, fly ash was used as a filler in this study to further improve the performance of polymer concrete since its use in polymer concrete has been documented to give superior mechanical characteristics and lower water absorption. FA was used as a filler in this study to further improve the performance of polymer concrete since its use in polymer concrete has been documented to give superior mechanical characteristics and lower water absorption. As a result, fly ash may be a highly useful substance for increasing the strength of polymer concrete. Based on the most recent research, the best-known PC performance may be obtained at a volume ratio of resin to FA matrix of 60:40 for creating a perfect PC mix.

Polyester Resin

One of the most significant ingredients in the production of polymer concrete is resin, which bonds all the elements together for increased strength. In this study, REVERSOL

P 9509 resin was used. Berjaya Bintang Timur Sdn. Bhd. (Malaysia) provided the resin. Bhd. REVERSOL P 9509 resin was mixed with Methyl Ethyl Ketone Peroxide (MEKP) as a catalyst. REVERSOL P 9509 resin is displayed in Table 1.

Table 1
Property of polyester resin (Parker & Moffett,1954)

Property	Value	Test Method
Specific Gravity	1.12	
Volumetric Shrinkage, %	8	
Tensile Strength, MPa	62	BS2782 – 320C
Elongation at Break, %	2.2	BS2782 – 320C
Water Absorption 24 hr at 25°C, mg	20	BS2782 – 430A
Deflection Temperature (under load 1.80 MPa), °C	55	BS2782 – 121A
Barcol Hardness (Model GYZJ 934-1)	40	BS2782 – 1001

Polypropylene Fibre (PPF)

Polypropylene fibre (PPF) was used in this study as fibre reinforcement to produce fibre-reinforced polymer concrete (Figure 1 and Table 2). Polypropylene fibres have been used for years to reinforce concrete and cement mortar. The fibres limit the spread of cracks and positively impact several concrete properties. Polypropylene fibres that have been geometrically distorted or changed are frequently employed to increase the material's adherence to the cement matrix. The fibres have an impact on the mortars' bending strength. The bending strength of mortars reinforced with fibrillated fibres has been shown to have significantly increased. Aside from that, the effects of polypropylene fibre on the physical and mechanical properties of concrete, such as its workability, compressive strength, stiffness, and flexibility, as well as its resistance to impact and abrasion and its ability to withstand the effects of freezing and thawing, as well as its cost, durability, and friendliness to the environment, need to be studied (Blazy & Blazy, 2021; Broda, 2016).

Figure 1. Polypropylene Fibre (PPF) (Blazy, 2021; Broda, 2016)

Table 2
Physical properties of PP fibre

Property	Value
Specific Gravity	0.91 gr/cm^3
Diameter	22µm
Width crossing	Circular
Melting point	160 - 170^{O}C
Water absorption	0
Torsion resistibility	400 -350 MPa

This present study utilised PPF at relatively low volume fractions to control plastic shrinkage cracking in the polymer concrete. PPF was added to polymer concrete in different percentages of 0.12%, 0.16%, and 0.20% to reveal the strength of polymer concrete reinforced with polypropylene fibres.

Concrete Mixture Properties

Polymer concrete mixtures are prepared at a volume ratio of 60: 40: 1.35 (resin + hardener; fly ash; coarse particles). Polypropylene fibre (PPF) was added (0%, 0.12%, 0.16%, and 0.2%) mixture weight to improve the mechanical qualities of polymer concrete. Furthermore, the polymer concrete PC properties and polypropylene fibre PPF are shown in Tables 3 and 4. respectively. According to Ferdous et al. (2020) study, the ideal resin-to-filler ratio is 60:40 to produce a long-lasting polymer concrete with an even distribution of aggregates, and the ideal matrix-to-aggregate ratio is 1:1.35 to obtain a suitable mix of cost, durability, and mechanical qualities. The polymer concrete mixture ingredients are shown in Figure 2. Polymer concrete was cast in four main stages. The volume required for each mix was modest and easy to handle; therefore, all the specimens were mixed by hand. Because of the rapid hardening, the specimens had to be done and finished one at a time rather than all at once.

Figure 2. Materials used in the preparation of polymer concrete mixture

Table 3
Polymer concrete (PC) mixture properties

Ratio	Resin + Hardener + Filler		Aggregate
	1		1.35
Volume fraction (%)	Resin + Hardener	Filler	
	60	40	
For 1 - cylinder specimen (g)	74.12 g	67.04 g	330.38 g
For 1 - prism specimen (g)	58.98 g	53.35 g	262.91 g

Table 4
Polypropylene fibre (PPF) content on polymer concrete (PC) specimens

Specimens	Polypropylene Fibre		
	0.12%	0.16%	0.20%
For 1 - cylinder specimen	0.57 g	0.75 g	0.94 g
For 1 - prism specimen	0.45 g	0.60 g	0.75 g

The 5 mm single-size aggregates were sieved and washed to remove contaminants that could interfere with the polymer concrete hardening process. The resin and hardener were mixed in a separate bowl at a weight ratio of 100:32 to create a reactive mixture that retains its fluidity, ensuring an ideal connection between the polymer matrix and the aggregates. The resin and hardener were combined for 120 minutes before being completely poly-condensed until a uniform colour was achieved. The fly ash was then added to the resin mixture and mixed until homogenous. The coarse aggregate was then added to the matrix and stirred for around 5 minutes to create a new polymer concrete. After the previous process, the required fibres were added to the polymer concrete. To ensure that the fibres were evenly distributed throughout the concrete, the mixture was stirred for 3 minutes until all the aggregates were coated with a polymer. At that point, the mixtures were put into the moulds. Finally, the mixture was compacted into three equal layers on a compaction machine, as illustrated in Figure 3, to achieve the required density. The specimens were cast and kept at room temperature for 24 hours to harden completely. After 24 hours of harding, all the specimens were cured for 7 days at room temperature (20°C) with 30% relative humidity before being examined. Because of its fast-curing characteristic, polymer concrete can achieve a strength of roughly 70% to 75% after one day of curing at room temperature, whereas typical Portland cement concrete can only achieve a 20% strength growth of its 28-day strength in one day. Although higher temperature curing speeds up the curing of polymer concrete, most research agrees that the optimum curing period for polymer concrete is 7 days since the compressive strength of PC is reported to become consistent after 7 days of curing (Ferdous et al., 2020).

(a) (b) (c)

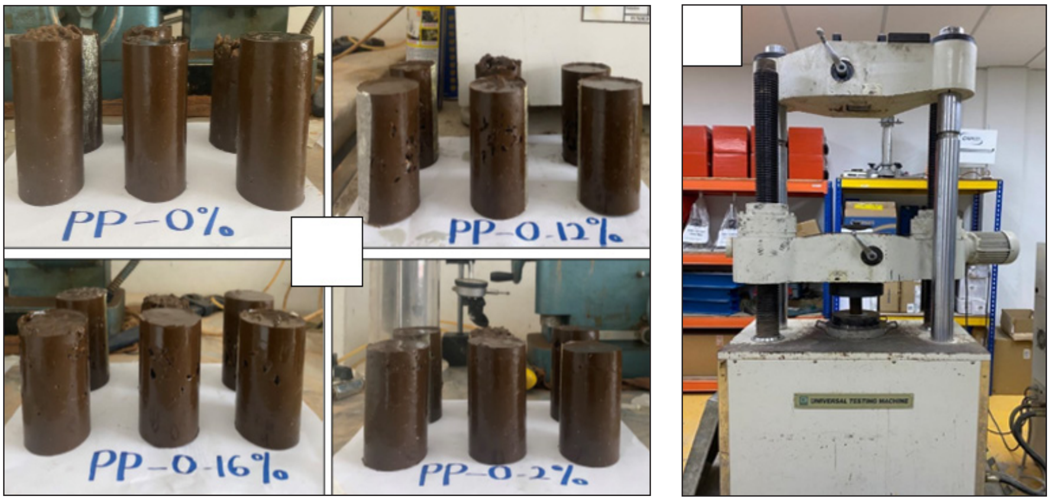
Figure 3. (a) A uniform colour of resin and hardener was obtained, (b) A fresh polymer concrete mixture with the addition of PP Fibre, and (c) The specimens were compacted using a compaction machine

Mechanical Properties

The effects of polypropylene fibre rates of 0.12 %, 0.16 %, and 0.2 % on the compressive strength, splitting tensile strength, and flexural strength of polymer concrete were examined. The tests were carried out at UNITEN's BD Laboratory using the Universal Testing Machine (UTM) as the testing instrument.

Compressive Strength. The compressive strength test was conducted on specimens of the cylinder (50mm × 100mm). According to ASTM C39 (ASTM, 2001), three specimens were tested for each mixture (Figure 4a). The specimen was weighed, and all the essential data, such as the diameter, length, and weight, was entered into the software. The cylindrical specimen was then vertically positioned in the centre of the UTM machine, as indicated in Figure 4b. The load was then applied to the specimens until they failed to acquire the results. The highest load achieved during the test was divided by the cross-sectional area of the specimen in Equation 1. It determined the specimen's compressive strength. The strength results obtained from the investigation will be influenced mostly by the size and shape of the specimen, the mixing procedure used, and the temperature and moisture conditions during curing.

$$\text{Compressive strength} = \frac{\text{Maximum load applied}}{\text{Cross} - \text{sectional area}} \quad (1)$$



(a) (b)

Figure 4. (a) Polymer concrete with various PP Fibre contains, (b) Compression machine used for axial and lateral compression of polymer concrete

Indirect Tensile Strength. Meanwhile, the indirect tensile strength tests were conducted on 50 mm × 100 mm specimens according to ASTM C496. The specimens are fixed horizontally in the middle of the UTM machine (Figure 5). The forces were constantly delivered at a steady rate until the specimens failed. The indirect tensile strength test procedure includes applying a diametric compressive force along the length of a cylindrical concrete specimen at a rate that matches within a prescribed range until failure occurs. This loading causes tensile stresses in the plane holding the applied load and rather strong compressive stresses in the surrounding area. Because the areas of load application are in a condition of tri-axial compression, tensile failure occurs rather than compressive failure. It allows them to endure significantly higher compressive loads than would be suggested by a uniaxial compressive strength test result. The tensile strength was calculated using Equation 2.

$$T = \frac{2P}{\pi l d} \tag{2}$$

Figure 5. Lateral compression load of polymer concrete

Where;
T = splitting tensile strength (MPa);
P = maximum applied load indicated by the testing machine (N);
l = length (mm); and
d = diameter (mm).

Flexural Strength Test. Flexural strength, also known as modulus rupture, is one of the most significant criteria when developing polymer concrete. It determines the concrete's capacity to withstand bending stresses caused by the load. The flexural strength test used a beam with 25 mm × 25 mm × 250 mm dimensions (Figure 8). A three-point flexural strength test (Figure 6) was conducted on polymer concrete specimens according to ASTM (2016). Due to the smaller beam size used in this study, the spans and distance between the loading head and the supports of the flexural testing machines were changed to assess the strength of the specimens. It is to confirm that the specimens were positioned correctly to avoid any possible inaccuracies in the results. Furthermore, the surface of the specimens must be free of any impurities for the test result to be of high quality. The load will then be applied perpendicular to the face of the specimen at a constant pace until it reaches the breaking point without shock. The maximum load obtained was then computed as follows (Equation 3):

$$R = 3PL \,/\, 2bd^2 \tag{3}$$

Where;
R = modulus of rupture (MPa),
P = maximum applied load indicated by the testing machine (kN),
L = span length (mm),
b = average width of specimen (mm), and
d = average depth of specimen (mm).

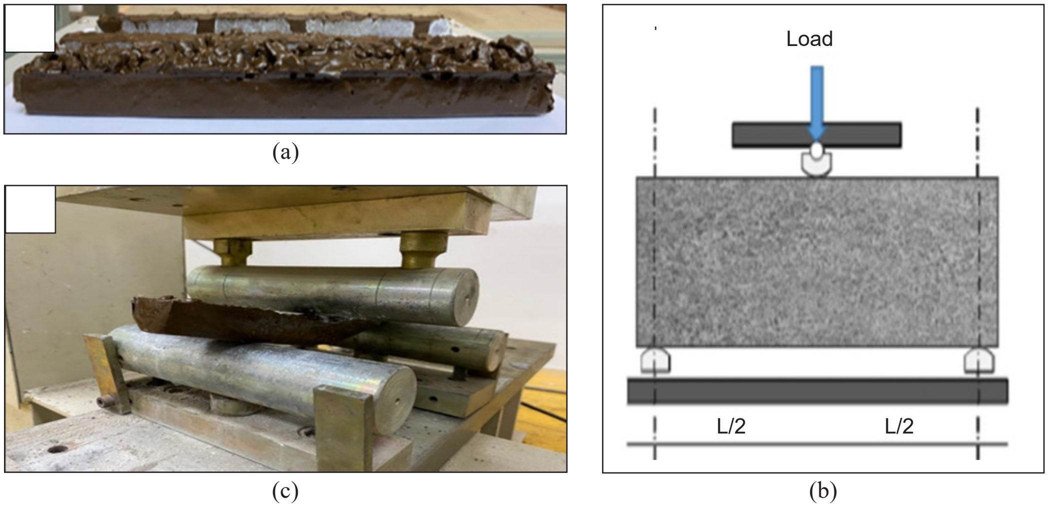


Figure 6. (a) Beam specimens, (b) ASTM C293–Centre Point Loading (ASTM, 2016), (c) Centre point loading applied on the beam

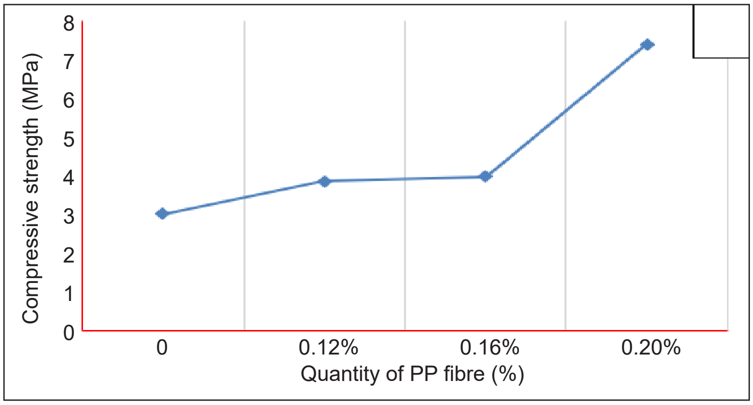
RESULTS AND DISCUSSION

The results characterise the mechanical properties of polypropylene fibre-reinforced polymer concrete. Due to the different fractions of polypropylene fibre being integrated into the polymer concrete (PC), the behaviour of each amount was monitored to determine the effects on the strength of the polymer concrete (PC) and compared to previous studies. The Compressive Strength Test, Indirect Tensile Strength, and Flexural Strength Test were the three types of tests used to explore the behaviour of PP Fibre in polymer concrete.

Compressive Strength

Figure 7 shows the average compressive strength for each mix. This test determines whether the polypropylene fibre-reinforced polymer concrete is conducted properly. Resin content, fly ash content, polypropylene fibre content, quality of material, and quality control during concrete production are the main factors that affect the compressive strength of concrete. From the results, the polypropylene fine PPF reinforcement significantly affects the compressive strength of polymer concrete. The compressive strength increased with increasing the content of polypropylene fibre PPF. The results showed that adding 0.12%, 0.16%, and 0.2% polypropylene fibre increased the compressive strength of polymer concrete by 27.81%, 31.79%, and 145.03%, respectively. Furthermore, as shown in Table 5, fibre-reinforced polymer concrete has a higher strength than non-fibrous polymer concrete.

Because of the continual compression force exhibited in Figure 7 of the fibre polymer concrete sample, the cracks have begun to distort. As the load increases, more cracks will appear until it reaches a fibre (Figure 7b). The results are consistent with Hsie et al.



(a)

(b)

Figure 7. (a) Compressive strength of polymer concrete containing various percentages of Polypropylene fibre reinforcement, (b) Failure behaviour Polymer concrete with 0.16% of PP Fibre

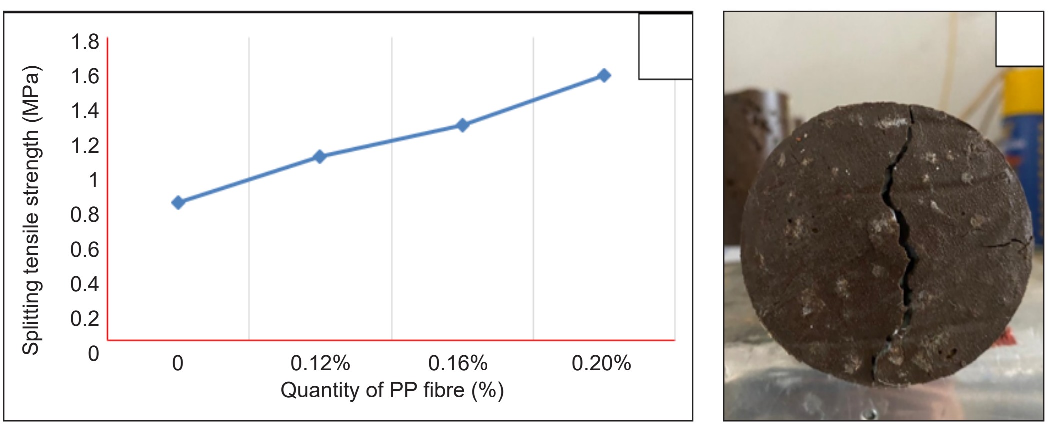
Table 5
The compressive strength of polypropylene fibre-reinforced concrete

Specimens	Quantity of Fibre (%)	Compressive Strength Average (MPa)	Percentage increment of strength (%)
Mix 1	0	3.02	-
Mix 2	0.12	3.86	27.81
Mix 3	0.16	3.98	31.79
Mix 4	0.20	7.40	145.03

(2008). It was found that adding polypropylene hybrid fibre to concrete resulted in more strength than using only a single fibre. With the addition of hybrid polypropylene fibre, the compressive strength increased by 14.60% to 17.31%, the splitting tensile increased by 8.88% to 13.35%, and the modulus of rupture increased by 8.99% to 24.60%. In a study by Marciano, reinforcing carbon fibre in the PC results in a 16% increase in compressive strength, whereas only an 8.7% increase in compressive strength was recorded when glass fibre reinforcement was used. However, when PP fibre was added to the polymer concrete in this investigation, compressive strength values expanded compared to carbon and glass fibre (Fluminense, 2014). The greater tensile stress in the polymer concrete due to the crack path perpendicular to the fibre matrix surfaces causes de-bonding between the fibre matrix surfaces. Due to the presence of the de-bonding crack earlier, a blunting process happened at the tip of the fracture when it eventually reached the interface. As a result, the crack-tip stress concentration was lowered, creating a diverting path for the crack and even preventing additional cracks. Because the fracture was blunted, stopped, and redirected, the fibrous polymer concrete cylinders could withstand more compressive stress, making them stronger than non-fibrous polymer concrete cylinders (Song et al., 2005).

Indirect Split Tensile Strength

The tensile strength of the concrete generally influences the extent and size of cracking in the structure. However, concrete is fragile in tension because of its brittle nature. Therefore, polypropylene fibre was added to investigate improvement. Figure 8a shows the results of the indirect split tensile strength of polymer concrete with different contents of polypropylene fibre PPF. Increasing the volume of PP fibre in the normal concrete increased the split tensile strength and flexural strength of the concrete mix design. The rupture modulus will be reduced with an additional 0.16% PP Fibre. Unfortunately, even though investigations into reinforcing PP fibre in Portland cement concrete have yielded reasonably large positive results, no polymer concrete experiments have been conducted. The splitting tensile strengths of polypropylene fibre-reinforced polymer concrete increase as the volumetric ratio of PP fibre increases. Non-fibrous polymer concrete has a tensile strength of 0.82 MPa, but adding 0.12%, 0.16%, or 0.2% PP Fibre raises the strength to 1.09 MPa, 1.28 MPa, and 1.57 MPa, respectively (Table 6). Meanwhile, compared to control polymer concrete, polymer concrete containing 0.2% polypropylene fibre PPF increased by 91.46% due to the advantages of PP fibre having high tensile strength properties.



(a) (b)

Figure 8. (a) Splitting Tensile Strength of polymer concrete PC with different polypropylene fibre PPF reinforcement, (b) Splitting of cylinder specimens

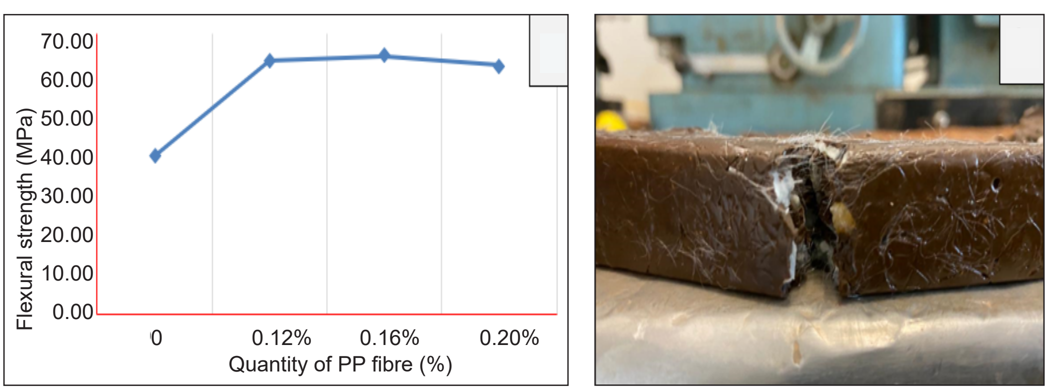
Table 6
Indirect tensile strength of polymer concrete with different contain PPF

Specimens	Quantity of Fibre (%)	Splitting Tensile Strength Average (MPa)	Percentage increment of strength (%)
Mix 1	0	0.82	-
Mix 2	0.12	1.09	32.93
Mix 3	0.16	1.28	56.09
Mix 4	0.20	1.57	91.46

When the stress is continuously applied to the cylinder specimens, they split until they fail. The addition of fibres in the PC, on the other hand, aids in support of the full load, hence boosting strength as stress is passed from the matrix to the fibres. As a result, the fibres aid in the strengthening of the matrix's divided parts. When compared to unreinforced control polymer concrete, the stress transferred improved the tensile strain capacity of the polypropylene fibre reinforced polymer concrete, and thus the reinforced polymer concrete's splitting tensile strength increased (Song et al., 2005). Aside from that, due to the huge amount of PP fibre that crossed the split sections, 0.2% fibre inclusion in polymer concrete resulted in higher strength than 0.12% and 0.16%. In general, the number of fibres intersecting the fracture surfaces affects the splitting tensile strength of fibre-reinforced polymer concrete. The cylinder specimens were cut into two halves along their vertical plane at the end of the test, as shown in Figure 8b.

Flexural Strength

Flexural strength, also known as bending strength, or transverse rupture strength, is a material property defined as the maximum stress in a material just before it yields in a bending test. Figure 9 displays the flexural strength of polymer concrete containing 0.12%, 0.16%, and 0.2% PPF, shows that the flexural strength of fibre-reinforced polymer concrete is higher than non-fibrous polymer concrete, with a maximum value strength of 64.42 MPa at 0.16% fibre addition. Increasing the PPF content leads to the flexural strength of fibre-reinforced polymer concrete having the opposite trend to its splitting tensile and compressive strength. Increasing the fibre content from 0% to 12% resulted in a 60.36% increase in flexural strength while increasing the fibre content by 0.16% resulted in a 62.99% increase in strength. The flexural strength of the polymer concrete is reduced from 64.42 MPa to 62.13 MPa when 0.20% PP Fibre is added, as shown in Table 7.



(a) (b)

Figure 9. (a) relationship between flexural strength and against PPF dosage, (b) failure behaviour of polymer concrete containing 16% PPF under flexural strength test

Table 7
Flexural strength of polymer concrete with different percentages of PPF

Specimens	Quantity of Fibre (%)	Flexural Strength Average (MPa)	Percentage increment of strength (%)
Mix 1	0	0.82	-
Mix 2	0.12	1.09	32.93
Mix 3	0.16	1.28	56.09
Mix 4	0.20	1.57	91.46

The fibres intersected the cracks that developed in the tension area of the reinforced beam, increasing flexural strength. By fitting into the crack so that the fibres' rubbery qualities come into place, these fibres mend the separation caused by the facial crack. It will minimise the pressure in the crack-tip surrounding the area formed by micro-cracks and increase the strength of the polymer concrete by giving an additional buffer in terms of energy that can be absorbed (Song et al., 2005). Based on the appearance of the sample, Figure 9b shows that PP Fibre reinforced polymer concrete has the same flexural strength as other types of fibres. Numerous studies demonstrate that when the resin content of polymer concrete increases, the compressive and flexural strengths likewise increase (Gagandeep, 2021; Otoom et al., 2022; Varun & Kumar, 2021).

A study conducted by Saribiyik et al. (2013) showed that compressive strength increases by about 7% when resin dosage is increased, while flexural strength is unaffected. Resin and quartz aggregates were added to the polymer concrete in the following ratios: The workability, compressive strength, and flexural strength of these materials were tested to evaluate the relationship between polyester percentage and strength. Similarly, Jafari et al. (2018) discovered that increasing the epoxy resin dosage and coarse aggregate size boosted the compressive strength of polymer concrete in destructive tests based on their experimental results. For the most part, it is seen that as the resin dosage is increased, the strength of the resin grows as well. However, as the resin dosage increases, the strength diminishes or remains unchanged. As a result, it was determined that a resin dose of 12% to 16% by weight of polymer concrete was the most effective.

Furthermore, the study by Gorninski et al. (2007) found that adding 3.5% steel fibre to a concrete mix increased the strength by 40%. Jo et al. (2008) discovered that adding nanoparticle fibre to polymer concrete increased its strength by approximately 38%. As a consequence, it can be concluded that reinforcing PP fibre in the PC is one of the most suited fibres for use in polymer concrete, as it produces a higher flexural strength of up to 63%, whereas other types of fibre produce a lower flexural strength.

CONCLUSION

This experiment found that polypropylene fibre reinforcement in polymer concrete offers exceptional mechanical performance. Compressive strength studies showed that as the amount of polypropylene (PP) fibres increased, so did the compressive strength of polymer concrete. The amount of PP fibre in polymer concrete makes the splitting tensile strength of the concrete stronger.

The flexural strength of fibre-reinforced polymer concrete, in contrast to the compressive and breaking tensile strengths, has demonstrated a trend opposite to the rise in the fraction of PP fibre employed in the mix. The results imply that fibre reinforcement is a viable option for enhancing the mechanical characteristics of polymer concrete, and polypropylene fibre has demonstrated potential as an additive for polymer concrete. Furthermore, the study discovered that 0.16% PP Fibre was the best fibre percentage to use in polymer concrete. The results showed that adding PP Fibre to the polymer concrete strengthened it in the compressive, splitting tensile, and flexural tests. Each test's results were thoroughly explained, and a graph was created to show the relationship between the strength measured and the fibre intake.

Therefore, these results from experiments have demonstrated that PP Fibre significantly impacts the mechanical characteristics of polymer concrete. The workability of fibre-reinforced concrete must be considered because it can degrade significantly when too many fibres are used in its composition. Additionally, it should be noted that the statement "greater fibre content-better qualities" is not always accurate. In other words, polypropylene fibres enhance the material's qualities, but only up to a specific dosage, which, if surpassed, has adverse effects. When choosing the ideal fibre content, it is crucial to consider the mixture's composition and the characteristics of the fibres (material, form, and dimensions: length, diameter, and slenderness). Sustainable development has benefited from polypropylene fibre-reinforced concrete's ecological and economic advantages. A prospective application for polypropylene fibre-reinforced concrete is in public places. Using concrete with improved qualities will unquestionably be advantageous because they are exposed to unfavourable environmental conditions, impact damage, surface abrasion, and vandalism. Decorative pavements, fountains, sculptures, artificial rocks, beaches, exotic scenery, door surrounds, and skate parks can all be created with polypropylene fibre-reinforced concrete.

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