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Mechanical performance of concrete reinforced with polypropylene fibers (PPFs)

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Abstract

Fibers are one of the most prevalent methods to enhance the tensile capacity of concrete. Most researchers focus on steel fiber reinforced concrete which is costly and easily corroded. This study aims to examine the performance of polypropylene fiber reinforced concrete through different tests. PPFs were added into concrete blends in a percentage of 1.0%, 2.0%, 3.0%, and 4.0% by weight of cement to offset its objectionable brittle nature and improve its tensile capacity. The fresh property was evaluated through slump cone test and while mechanical strength was evaluated through compressive strength, split tensile strength flexure strength, and flexure cracking behaviors after 7-, 14-, and 28-days curing. Results indicate that slump decrease with the addition of PPFs while fresh density increase up to 2.0% in addition to PPFs and then decreases. Similarly, strength (compressive strength; split tensile strength, and flexure strength) was increased up to 2.0% addition of PPFs and then decrease gradually. It also suggests that Ductility; first crack load, maximum crack width, and load-deflection inter-relations were considerably improved due to incorporations of PPFs.

Keywords

Polypropylene fiber, workability, fresh density, compressive strength, split tensile strength, flexure cracking behavior

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Introduction

Concrete is a highly used construction substance in the construction field because of its high stability and structural strength.[1,2] Even if concrete behavior is governed significantly by its compressive strength, the tensile strength is also most important for the durability of concrete. The tensile capacity of concrete is much lower as compared to compressive strength which results in brittle failure without any warning or deformation before failure. Various kinds of fibers are added to concrete to enhance the tensile strength of concrete. Mostly Steel fiber reinforced concrete can resist shock and high ductility,

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flexural strength, tensile strength as well as Crack restriction, and fatigue resistance.

The structural integrity of concrete can be improved with the incorporation of fibrous materials in concrete. According to previous research, the shear and tensile capacity of reinforced concrete can be improved with nylon, polypropylene as well steel fibers.[3,4] The addition of polypropylene can improve the mechanical performance of concrete without increasing density.[5] Also reported that nylon and propylene slightly improve the engineering property of concrete particularly tensile strength.[6] It is been reported that polypropylene fibers improve concrete property considerably.[7]

A general observation is that tinny fibers are additionally imposing in decreasing the width of plastic shrinkage cracks than thick fibers according to past literature as given in ACI 544.5R-10.[8] The positive response of steel fibers added in concrete depends on various aspects such as diameter, length, aspect ratio, types, cross-sectional area, concrete mix design, water-cement ratio, method of mixing, etc.[9] Steel fiber reinforced concrete is most widely used in many civil engineering projects due to easy fabrication, low cost as well as high performance.[10,11] However, some studies reported that uneven addition of steel fiber results in negative effects on the workability of fresh concrete leading to the poor bond of fibers with surrounding concrete resulting in porous concrete and mechanical performance of fibers reinforced concrete decreased.[12–14]

Steel fibers efficiently improve the load-carrying ability of structural components which makes the structural behavior more ductile. Steel fibers reinforced concrete shows greater than 0.38% marginally increased the ultimate load-carrying capacity as well as ductility of slab.[15] Research displayed that unequal adding of SFs will affect the concrete uniformity and fluidity in mixing and even bonding of fiber, which ultimately affect mechanical performances.[16] Steel fibers considerably improve in the initial strength and the long-term strength of fiber reinforced concrete.[17–21] Steel fibers act as a crack restriction and not only just crack prevention. Steel fibers are well-known to increase the tensile strength of post-cracking behavior.[22] Tensile strength steel fibers reinforced concrete is much higher than conventional concrete.[23] Tests results indicate that raise in fiber quantity will result to improve ductility, toughness, and strength.[21,24] Modulus of elasticity of fiber concrete increases with an increase in the fiber quantity.[25] Adding of SFs in concrete not only enhances the strength but also the ductility.[18] They realized that fiber increased the peak pull-out load.[26] Steel fibers (SFs) can enhance the tensile capacity of concrete by about 40% as per past literature.[27] Moreover, the addition of steel fibers (SFs) helps in decreasing the permeability, segregation, bleeding porosity properties of concrete.[28–31]

Research shows that rheological properties (filling and passing ability) of self-compacting decreased with concrete of PPFs. Furthermore, the mechanical performance of concrete improved considerably up to 2.0% addition of PPFs.[32] Studies show that PPFs improve mechanical performance in terms of compressive strength, split tensile strength as well as flexure strength of concrete.[32,33] It has been reported that the mechanical performance of foam concrete considerably improved with the addition of PPFs.[34,35] PPFs improved concrete performance against acid attacks.[4] PPFs reinforced concrete, maximum tensile strength was achieved with the volume fraction of 1% which is a 52% increase when compared to reference concrete. Furthermore, it can be observed that the area under the curve for the PPFs concrete increased with increasing fiber content.[35] A study found that the inclusion of the PPFs at volume fractions of 0.75% and 1% improved the compressive and flexural strengths of the foamed concrete.[34] The inclusion of PPFs changed the brittle failure mode of foamed concrete to elastic–plastic behavior.[36] It has been found that the flexural strength of foamed concrete with densities in the range of 600–1400 kg/m^3 improved with the inclusion of PP fibers using volume fractions of up to 0.4%.[37]

A brief overview of existing literature shows that several studies investigated the performance of steel fiber reinforced concrete. Ahmad et al.[38] carried-out research on flexure cracking behavior of steel fibers reinforced concrete and reported a positive response. However, steel fibers are too costly and are easily corroded. Therefore, it is necessary to search for new fibers material instead of steel fiber which is economical and easily available. Also, further research was recommended[38] to evaluate flexure cracking behaviors of concrete with the incorporation of PPFs. Most researchers focus on the mechanical (compressive and split tensile strength) and durability performance of PPFs concrete. While fewer researchers focus on the ductility and flexure cracking behavior of concrete.

Therefore, the present study evaluates the mechanical performance of polypropylene fibers in terms of concrete ductility index, load defection relation, first crack load, maximum crack width, and flexure cracking behaviors of polypropylene fibers reinforced concrete. Polypropylene fibers were added in proportion 0%, 1%, 2%, 3%, and 4% by weight of cement. Test results depict that, workability decrease with the incorporation of PPFs while fresh density and strength increase up to 2.0% addition and decrease. Furthermore, the Ductility index, load defection relation, and flexure cracking behaviors of concrete considerably improved with the incorporation of polypropylene fibers.

Experimental program

Materials

Cement. According to ASTM C150,[39] Ordinary Portland cement Best way (Haripur, Pakistan) type-1 with 28 days compressive strength 42 MPa was used in this research. Table 1 shows the chemical composition and physical properties of cement used in this study.

Table 1. Physical and chemical property of OPC.

Chemical property	Percentage (%)	Physical property	Results
Ca0	65.7	Size	⩽75 μ
SiO_2	21.9	Fineness	95%
Al_2O_3	5.4	Normal consistency	39%
Fe_2O_3	4.7	Initial stetting time	36 min
MgO	4.5	Final stetting time	451 min
SO_3	1.9	Specific surface	322 m^2/kg
K_2O	1.4	Soundness	0.70%
Na_2O	1.3	Compressive strength	42 MPa (28-days)

Table 2. Physical property of polypropylene fibers.

Physical property	Results
Length	35 mm
Diameter	0.55 mm
Aspect ratio (L/d)	64
Tensile strength	415 MPa
Young's modulus	3.6 GPa

Table 3. Physical property of fine and coarse aggregate.

Physical property	Fine aggregate	Coarse aggregate
Size	0.075–4.75 mm	4.75–25 mm
Fineness Modulus (F.M)	2.83	4.2
Water absorption	4.28%	3.38%
Moisture content	1.93%	1.65%
Bulk density (kg/m^3)	1586	1535

Polypropylene fibers (PPFs). Polypropylene fibers were procured from Sika company (Islamabad Pakistan) having 35 mm long length with 0.55 mm diameter. Furthermore, Table 2 shows different aspects of PPFs used in this study.

Aggregate. Locally available natural sand was used as a fine aggregate (F.A) in all the mixes in saturated surface dry condition (SSD). Normal weight crush stone was used as coarse aggregate (C.A) in a saturated dry condition which was obtained from Margallah Wah Cantt Punjab Pakistan. Different tests were performed on aggregate to evaluate its properties. Particle size distribution curve (gradation curve) of fine aggregate and coarse aggregate were shown in Figure 1 while physical properties were given in Table 3.

Constant parameter. Quantity and cement type, quantity and type of aggregates, Water cement ratio and Mix design will be kept constant throughout the study. Furthermore, Figure 2 showed a complete flow chart of research.

Variable parameter. The dose of polypropylene fibers is the variable element in all Mixes, starting from 0% to 4% by weight of cement.

Superplasticizer. High range water reducing admixture (Chemrite-530) was used as a superplasticizer which is non-toxic and non-harmful under relevant conditions and protection issues. Chemrite-530 follows the requirements define by codes of ASTM[40] and EN[41] and ASTM. Typical properties of the superplasticizer used in this study are given in Table 4.

Tests and size of specimen

A slump cone will be used to measure the workability of fresh polypropylene fibers reinforced concrete as per ASTM C-476.[42] According to ASTM C39/C39M,[43] 6 × 12″ (cylinder) was used to find the compressive capacity of concrete after 7, 14, and 28 days curing. Similar to compressive strength, 12 × 12″ (cylinder) were cast and tested to measure tensile capacity as per standard given by ASTM C-496.[44] A beam of size (6 × 6 × 20″) was cast and tested to measure their flexure behavior. Three samples of each test were tested, and their average value was taken as a strength for that test.

Sample preparation method. The casting of the test sample and compaction was done with a tamper rod in three different layers manually having 25 blows per layer according to the method defined by ASTM C-31.[45] A total of five mixes of standard-size specimens were cast and then tested. To study the effect of polypropylene fibers on the behavior of hardened and fresh concrete, five mixes are prepared. Details of the mixes are provided in the following Table 5.

Results and discussion

Fresh properties

Slump test and density of fresh fiber reinforced concrete. Concrete compressive strength generally depends on the concrete workability. The poor concrete workability reduces the concrete compaction and increases porosity in concrete. The rise in porosity reduces the concrete density of concrete leading to less compressive strength. Density is

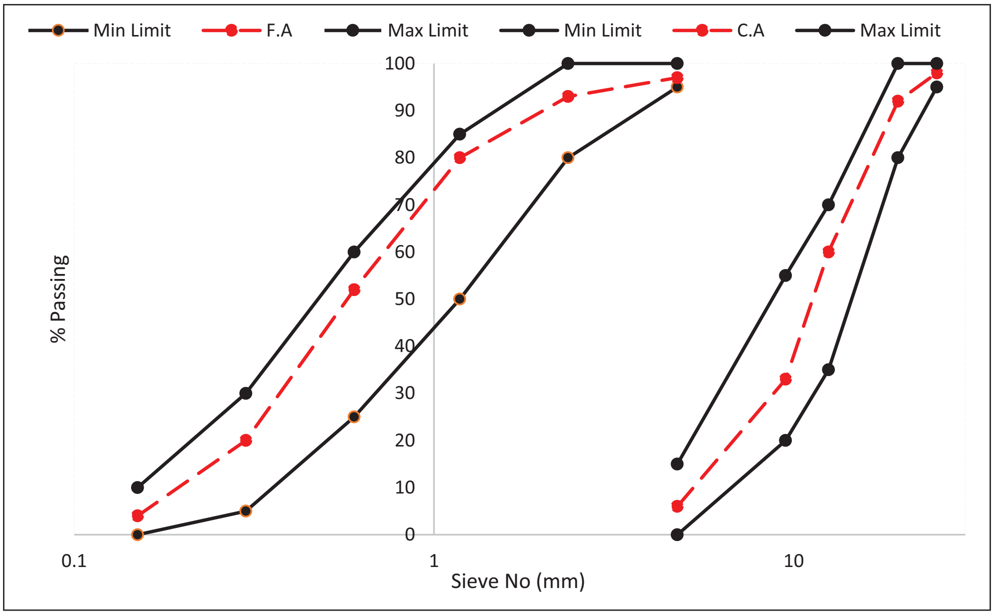

Figure 1. Gradation curve of aggregate.

one of the most important factors to be considered while designing concrete design. Workability, is defined by ACI 116, is the extent of how smoothly the concrete can be mixed, placed, compacted, and then be finished.[46]

Figure 3 shows concrete workability with the varying dosage of polypropylene fiber. Concrete workability decreased as the percentage of polypropylene fiber increased. Slump value of 0%, 1%, 2%, 3%, and 4% polypropylene fibers added to concrete were 53, 42, 34, 30, and 28 mm which were 20%, 35%, 43%, and 47% lower than from reference concrete as shown in Figure 3. This is due to the fact, that the number of polypropylene fibers in a concrete mix increases the surface area. Along with coarse aggregate, the mortar also needs to coat the surface fibers. This means additional mortar is required to coat the extra surface area of polypropylene fibers, therefore more cement paste is required for lubrication which results in the workability of concrete being reduced as the percentage of polypropylene fibers raised. Also, polypropylene fiber enhances the internal friction between concrete ingredients resulting in more paste to reduce the internal friction, leading to less workable concrete. A similar finding has been also reported that concrete workability reduced as the fibers percentage increased.[32,47,48]

The results of fresh concrete density with the varying dosage of polypropylene fibers were shown in Figure 4. The experiment outcome showed that fresh density increases as the ratio of polypropylene fibers increase up 2% addition and then decreases as compared to the control concrete. Maximum fresh density is obtained at 2.0% addition of polypropylene fibers whereas the lowest density was obtained at 0.0% addition of polypropylene fibers control concrete. The increase in fresh density of concrete blend with polypropylene fibers is due to crack prevention fiber as polypropylene fiber reinforced concrete has fewer cracks as compared to control concrete leading to denser concrete. However, at higher dosages, at 4.0% addition of polypropylene fibers, the compaction process becomes more difficult which results in porous concrete, leading to a less fresh density of concrete as compared to control. Therefore a higher dosage of polypropylene, a higher dosage of superplasticizer is required.

The correlation between fresh density and slump with varying percentage polypropylene fibers is shown in Figure 5. It is observed that a strong correlation exists between slump and density of fresh fibers reinforced concrete having an R^2 value greater than 90%. It is due to fact that density is the function of workability. Low workability leads to more voids in occupied space which results in ultimate less density.

Harden properties

Dry density. The dry density of concrete is an important parameter that influences the mechanical performance of concrete as well as the durability aspects of concrete. Higher dry density results in less voids in hardened concrete which leads to more compressive strength. Similar higher dry density results in less penetration of water and acid into the concrete body which ultimately results in more durable concrete as compared to less dry density concrete.

Figure 6 shows the dry density of concrete with different doses of PPFs. It can be observed that the dry density of concrete increased with the addition of PPFs up 2.0% and then decreased gradually. It can be also observed that

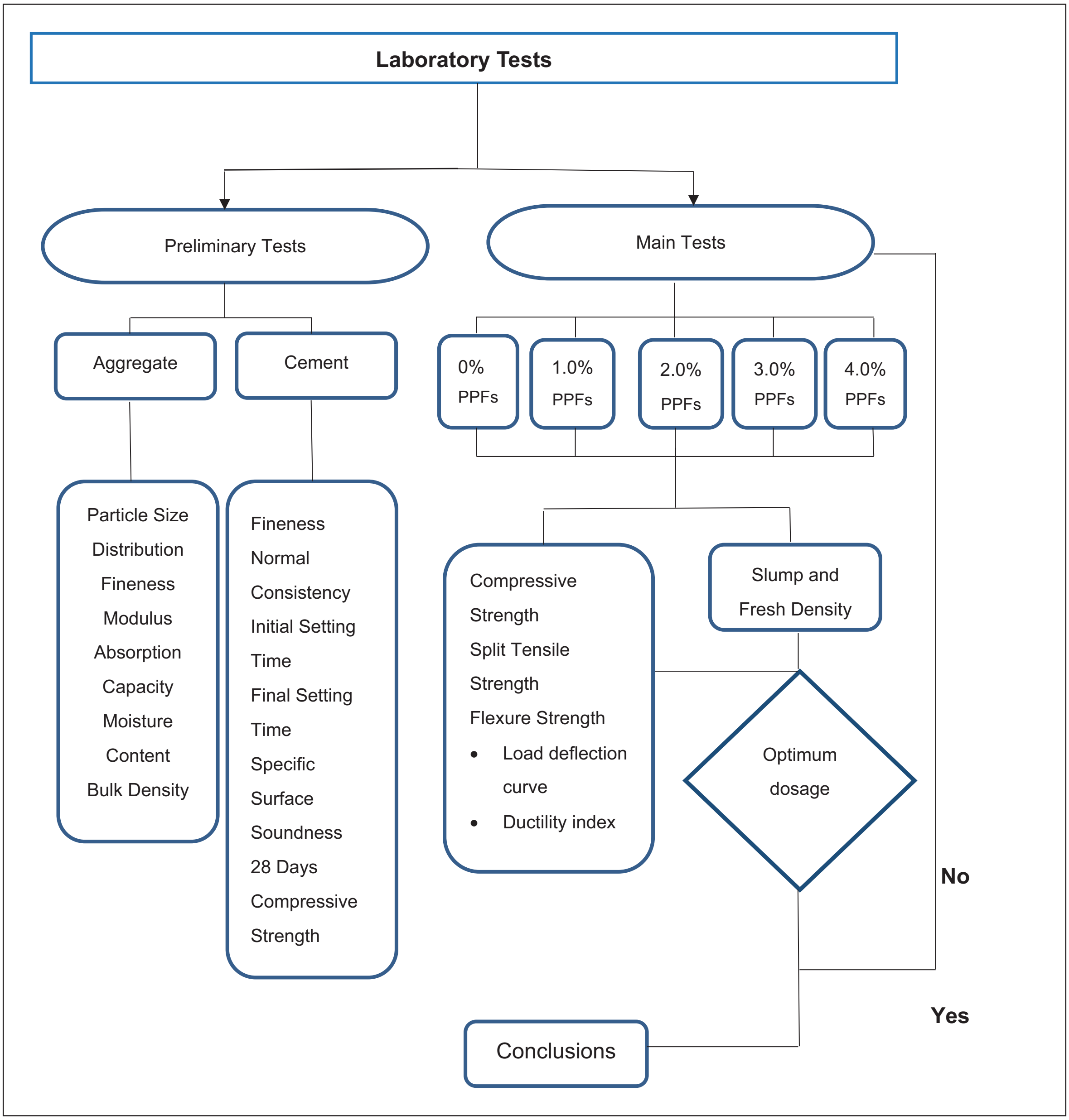

Figure 2. Flow chart of research.

Table 4. Physical property of Superplasticizer.

Property	Result
Color	Dark brown
Density	1.78 at 27°C
Chloride content	<0.2%
State (Physical)	Liquid

Table 5. Quantification of materials per m^3.

Materials (kg)	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Cement	425	425	425	425	425
Fine Aggregate (F.A)	625	625	625	625	625
Coarse Aggregate (C.A)	1270	1270	1270	1270	1270
Water	213	213	213	213	213
Superplasticizer	4.25	4.25	4.25	4.25	4.25
Polypropylene fibers	–	4.25	8.5	12.75	17

dry density is slightly lower than the fresh density of concrete. It is due to the evaporation of free water from concrete. All PPFs mix shows dry density greater than conventional concrete. It has been also reported that the dry density of concrete increased with the addition of PPFs up to 2.0% by weight of cement and then decreased due to lack of workability which results in more voids in hardened concrete. Minimum density is 2310 kg/m^3 at 0%

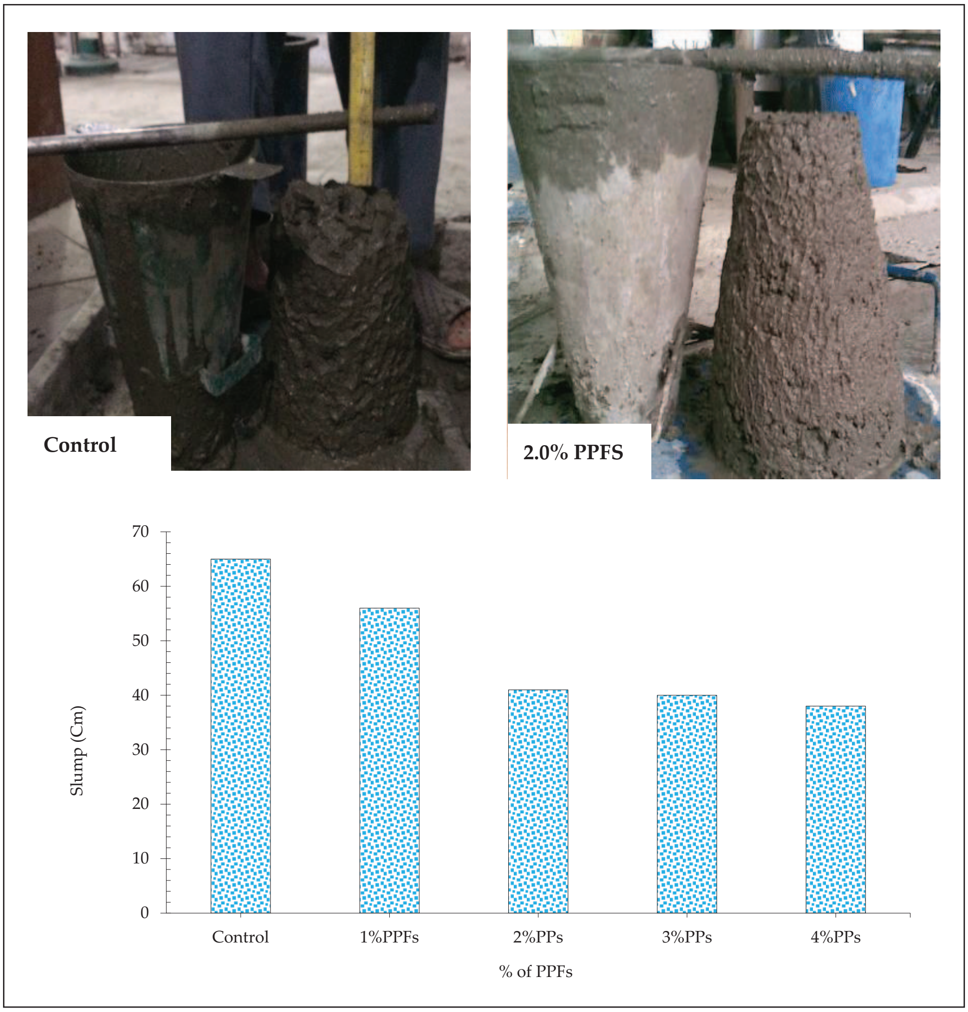

Figure 3. Slump test results.

addition of PPFs (control concrete) while maximum density is 2450 kg/m^3 at 2.0% addition of PPFs which is about 60% more than reference concrete. It is because, PPFs restrict the propagation of shrinkage cracks which results in less voids in hardened concrete, leading to more dense concrete.

Compressive strength. The ability of materials to resist the force when it is subject to compressive force is termed as the compressive strength of that material. According to the standard procedure defined by ASTM as ASTM C39/C39M[43] was used for the compressive strength test for standard size (300 mm length and 150 mm diameter) cylindrical specimens.

Figure 7(c) shows the compressive strength of concrete with varying dosages of PPFs. Compressive strength enhanced up to 2.0% incorporation of PPFs as compared to control. At 2.0% addition of PPFs in concrete results in maximum compressive strength at 28 days as compared to the control mix or reference mix. After reaching the peak strength, the control concrete cylinder fails in compression with a big crack at the end of specimens while in the case of PPFs reinforced concrete cylinder, a larger number of tiny cracks appeared at the middle section of the cylinder which ensures ductile failure as shown in Figure 7(a) and (b). However, compressive strength starts to decrease due to lack of workability particularly at higher dosages that is, beyond the 2% dosage. The improvement of compressive strength due to the addition of PPFs can be attributed to the confinement of PPFs on the concrete specimen. Laterally expansion produced under the application of compressive load which is resisted due to confinement which results to enhance compressive strength.[4,38] When the addition of PPFs is increased up to beyond 2.0%, this confinement can decrease transversal deformation crack of the sample and hence improve its capacity against compressive load. However, increasing the dosage of PPFs in particular higher dosage (beyond 2.0% addition of PPFs), due to lack of workability, the compaction process becomes more difficult leading to pores in hardening concrete, resulting in

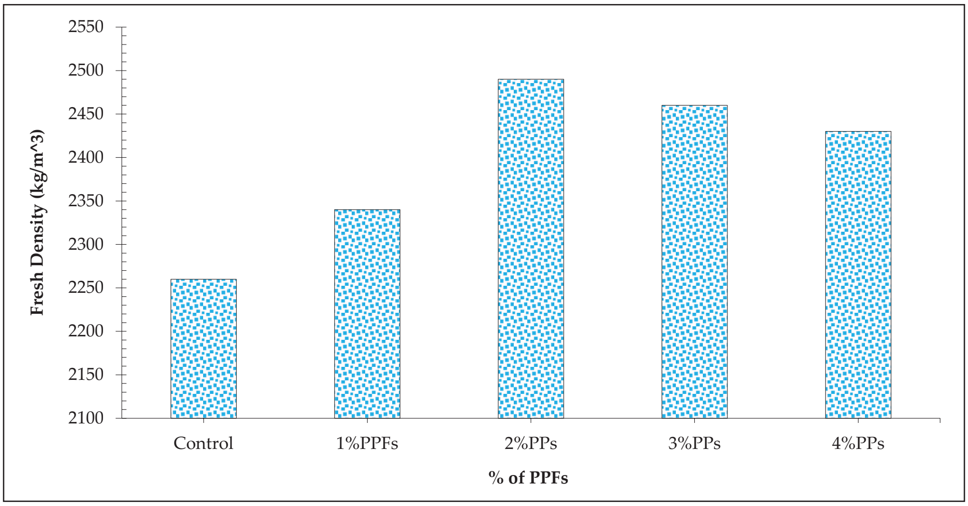

Figure 4. Fresh density results.

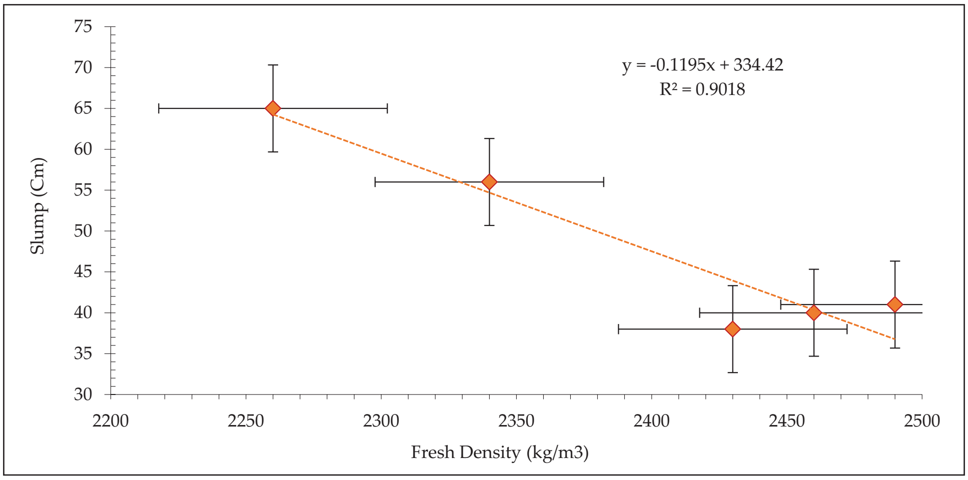

Figure 5. Correlation between slump and fresh density results.

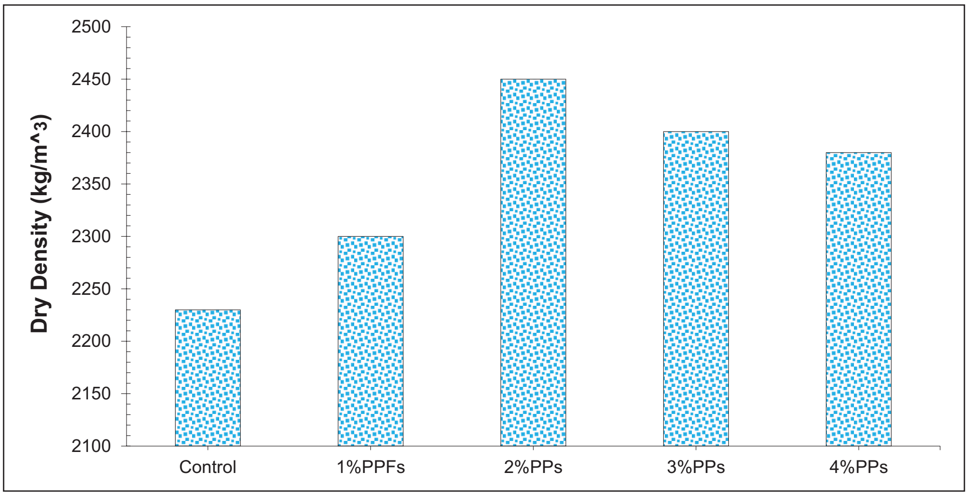

Figure 6. Dry density of concrete.

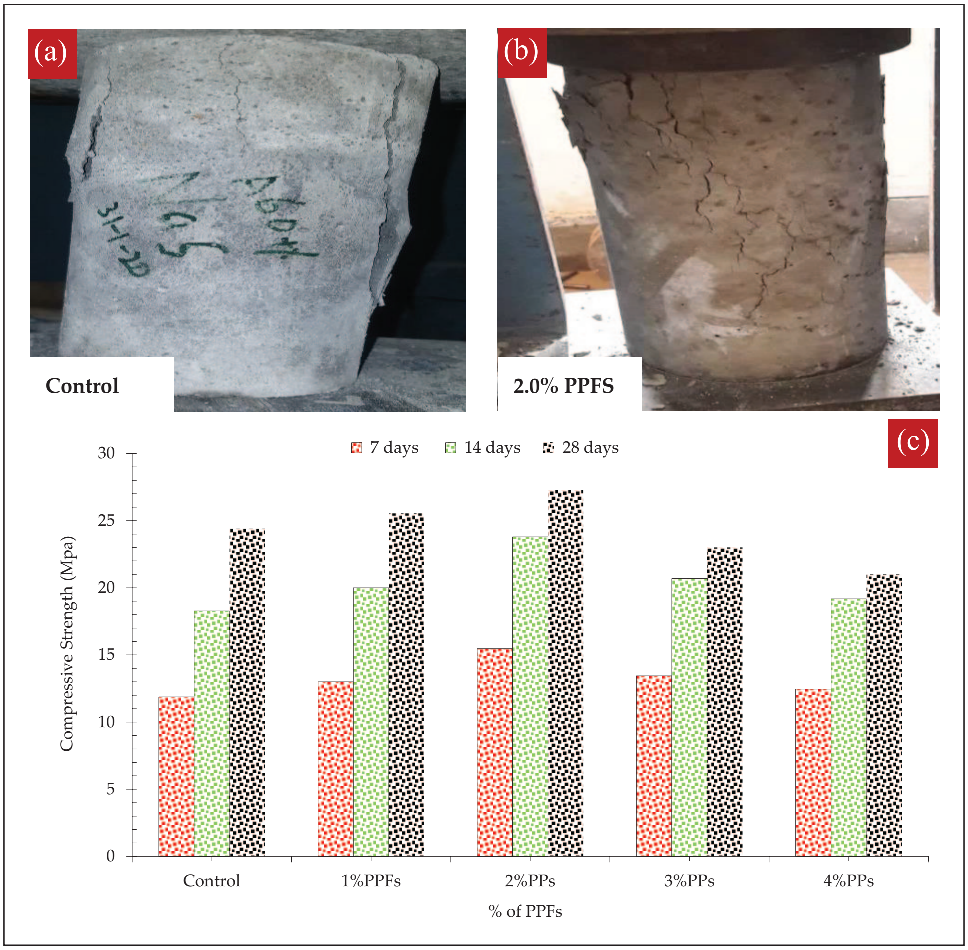

Figure 7. (a) Failure mode of control sample, (b) failure of 2.0%PPFs sample, and (c) compressive strength results.

less compressive capacity. Therefore, a higher dose of superplasticizer is required for a higher dose of PPFs. A similar finding is also reported by the past researcher.[17–21]

A relative analysis was also carried out in which 28 days compressive strength of control mix is considered is reference mix, from which different mix of varying percentages of PPFs is compared as shown in Figure 8. At 7 days curing, compressive strength is about 37% less than as compared to control (28 days) at 2.0% addition of PPFs. At 14 days curing, concrete compressive strength is only 3.0% less than reference concrete control (28 days) at 2.0% addition of PPFs. At 28 days of curing, concrete compressive strength is 11.8% higher than reference concrete at 2.0% addition of PPFs.

Split tensile strength. Split Tensile strength is the tensile stress produces due to applying compressive load in the compressive testing machine in such a way that concrete cylindrical specimen split in vertical diameter. It is called the indirect method to find the tensile strength of concrete. The direct method is not possible because of grip cylindrical sample satisfactory as well as eccentric load. Therefore, the direct tensile test is not a standardized method. After 7, 14, and 28 days of curing, split tensile was found according to ASTM C496-71,[44] of a standard cylindrical sample of 150 mm diameter and 300 mm length.

Figure 9(c) shows split tensile strength with varying percentages of polypropylene fiber from 0% to 4.0% in increments by 1.0%. Based on experimental test results split tensile strength increased as the percentage of polypropylene fiber raised to 2.0% addition of polypropylene fiber and then decreased as displayed in Figure 9(c).

After 28 days of curing, the highest split tensile strength was obtained at 2.0% addition of polypropylene fiber, and minimum strength was obtained at 0% addition of polypropylene fiber (control mix). It is because the flexibility of concrete increases due to the addition of PPFs by halting the formation of tension cracks or stopping the creation of cracks which results that tensile strength capacity of fibers reinforced concrete is much better than conventional concrete mix as shown in Figure 9(a) and (b). PPFs act as crack stoppers and not as cracks prevention. PPFs behave as crack stoppers and not as cracks prevention. Steel fibers are known to enhance the tensile capacity of post-cracking behavior.[22] However, beyond 2% dosage polypropylene fiber, compaction becomes more difficult due to lack of

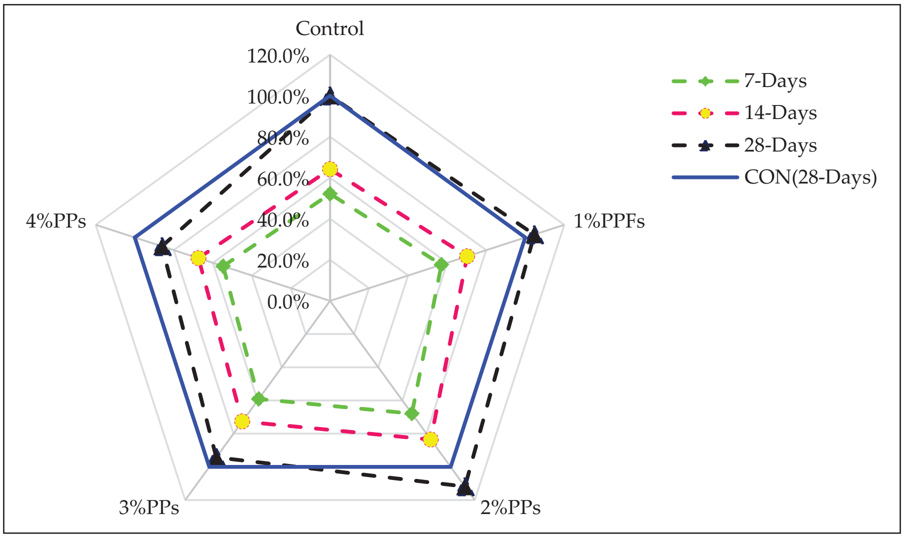

Figure 8. Relative analysis of compressive strength.

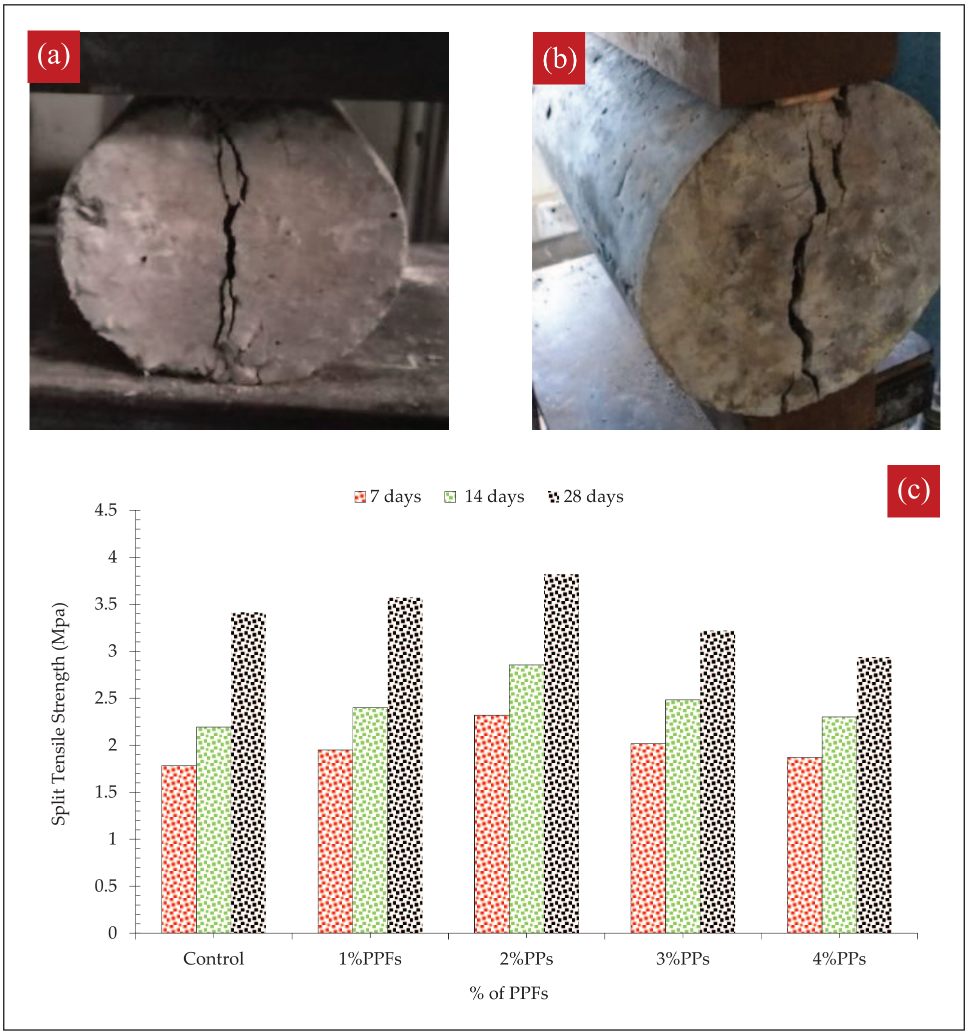

Figure 9. (a) Failure mode of control sample, (b) failure of 2.0%PPFs sample, and (c) split tensile strength results.

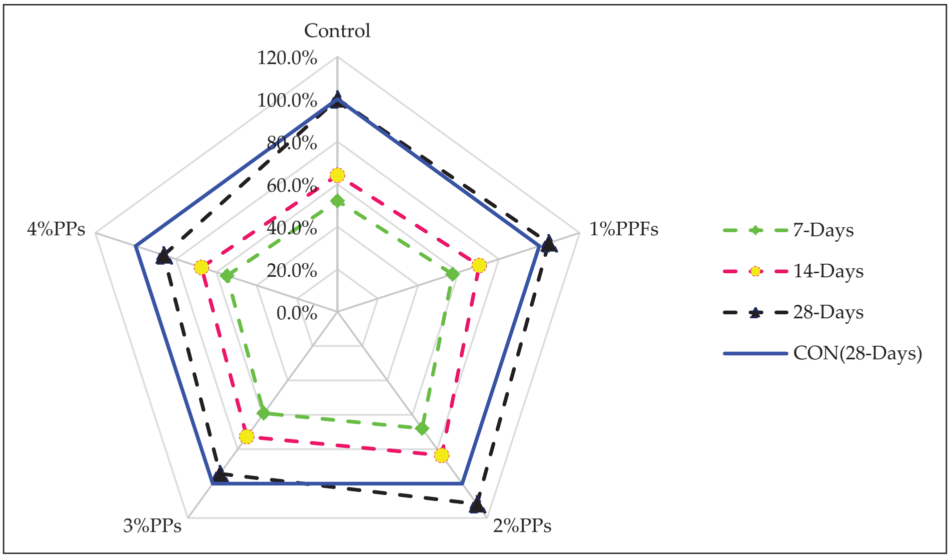

Figure 10. Relative analysis of split tensile strength.

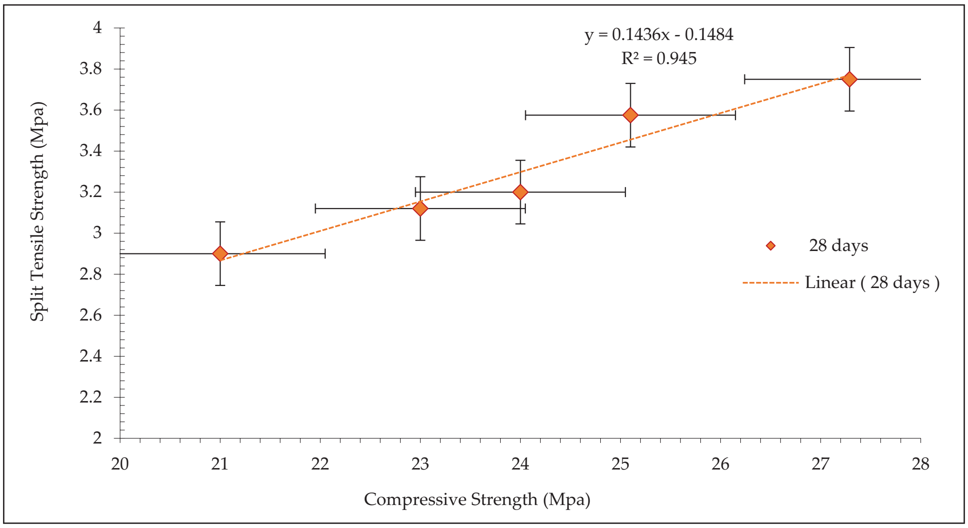

Figure 11. Correlation between compressive strength and split tensile strength.

workability resulting in porous concrete, leading to less split tensile strength being reduced.

A relative analysis was also carried out in which 28 days split tensile strength of control mix is considered is reference mix, from which different mix of varying percentages of PPFs is compared as shown in Figure 10. At 7 days curing, split tensile strength is about 33% less than as compared to control (28 days) at 2.0% addition of PPFs. At 14 days curing, concrete split tensile strength is only 17% less than reference concrete control (28 days) at 2.0% addition of PPFs. At 28 days of curing, concrete split tensile strength is 12.2% higher than reference concrete at 2.0% addition of PPFs.

Correlation between split tensile strength and compressive strength with varying percentage polypropylene fibers from 0% to 2.0% is shown in Figure 11. It has been reported Split tensile strength is a function of compressive strength.[38] Split tensile strength is approximately 10% to 15% of compressive strength.[4] It is observed that a strong correlation exists between compressive strength and split tensile strength with varying dosage percentages of polypropylene fibers reinforced concrete having an R^2 value greater than 90%.

Flexural strength. Flexural strength, or bending strength, or transverse rupture strength, or modulus of rupture is a material characteristic, which can be defined as the ability of the material to resist deformation.[49] Flexure test was carried out on beam specimens of 6 × 6 × 20″ as shown in Figure 12 at the ages of 7, 28 days curing.

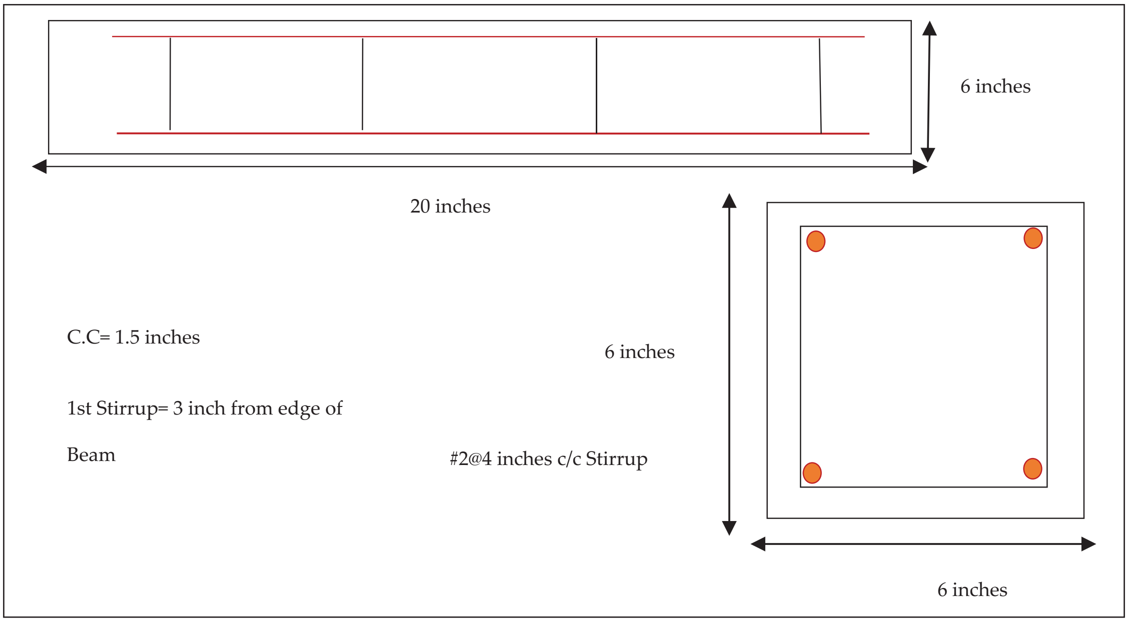

Figure 12. Beam details.

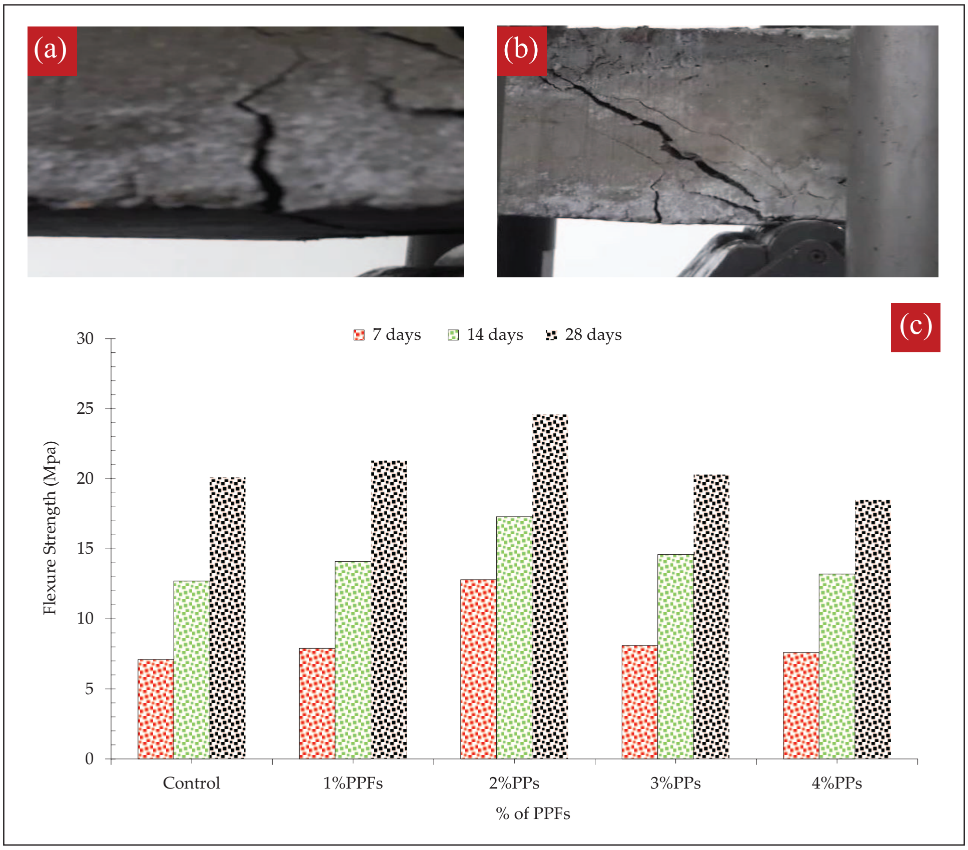

Figure 13. (a) The failure mode of control sample, (b) failure of 2.0%PPFs sample, and (c) flexure strength results.

Based on experimental work, the Flexure strength of varying percentages of polypropylene fibers at all ages was shown in Figure 13(c). It can be observed that flexure strength gradually increased up to 2.0% addition of polypropylene fibers and then gradually decreased had maximum flexure strength at all ages as compared to other

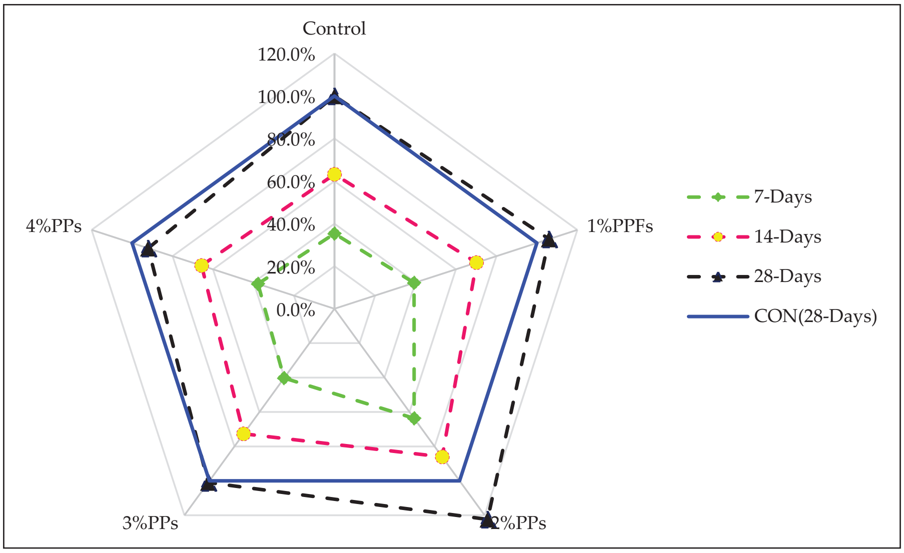

Figure 14. Relative analysis of flexure strength.

mixes. It has been also reported that fibers have displayed more considerable results on flexural tensile strength at up to 2.0% addition by weight of cement.[23] So, polypropylene fibers had maximum flexure strength when polypropylene fibers are 2.0% by weight of cement and minimum when polypropylene fibers are 0% control concrete. Maximum flexure strength obtained was 25 MPa while flexure strength of normal concrete was 20 MPa at 28 days curing. It is worth mentioning here that fibers more significantly affect flexure strength than compressive strength. As fibers enhance ductility, which blocks the propagation of cracks, and hence strength improved as per previous study.[22]

Control concrete beams were destroyed in the compression zone by concrete crushing with wide cracks perpendicular to the element axis, caused by bending. Beams carried the loads as long as the adhesion of concrete and steel was not exhausted, the beams reached the phase of successive cracks formation which concrete is failed earlier than steel casing compression failure as shown in Figure 13(a). On the other hand, which PPFs are added to concrete, beams fail shear as shown in Figure 13(b). There were diagonal cracks due to shear in the support zone. Perpendicular cracks appeared much later in the case of beams made of concrete with 2.0% of PPFs, due to their greater tensile strength. PPFs reinforced concrete beams till carried full load after the crack appeared which results in ductile failure of concrete beams.

A relative analysis was also carried out in which 28 days flexure strength of control mix is considered is reference mix, from which different mix of varying percentages of PPFs is compared as shown in Figure 14. At 7 days curing, flexure strength is about 37% less than as compared to control (28 days) at 2.0% addition of PPFs. At 14 days curing, flexure strength is only 14% less than reference concrete control (28 days) at 2.0% addition of PPFs. At 28 days of curing, concrete flexure strength is 23% higher than reference concrete at 2.0% addition of PPFs.

The correlation between compressive strength and flexure strength with varying percentage polypropylene fibers is shown in Figure 15. It is observed that a strong correlation exists between slump and density of fresh fibers reinforced concrete having an R^2 value greater than 90%.

Load deflection curve of beam. Curve Load deflection is a graphical relationship of deflection against the corresponding load. A comparison of load-deflection curves for both normal and polypropylene fiber beams was displayed in Figure 16. As it can be seen from Figure 16 that all the PPFs beams have higher values of the ultimate load as compared to the control concrete. It has been reported that increasing the fibers percentage results in increased peak ultimate flexure load more effectively which was about 2–3 times the control concrete.[26] As a comparison of the control mix, Beam with 2.0% PPFs (by weight of cement) shows the maximum ultimate peak flexure load. Also, 2.0% of PPFs show maximum toughness (area under the curve). It is due to fact that PPFs act as crack stoppers which delays the generation of micro-cracks. Also reported that raise in fiber quantity will result in improved ductility, toughness, and strength.[24] Adding of PPFs in concrete enhances not only the strength attributes but also the ductility of concrete which gives a warning (deformation) before failure.[18] Thus, PPFs are a viable solution to increase the mechanical performance of concrete but more important is that, offset the brittle of concrete.

Ductility index. Ductility is the ability of materials to sustain considerable plastic deformation before failure, which may be articulated as percent elongation or percent area decrease from a tensile test. To find the ductility of

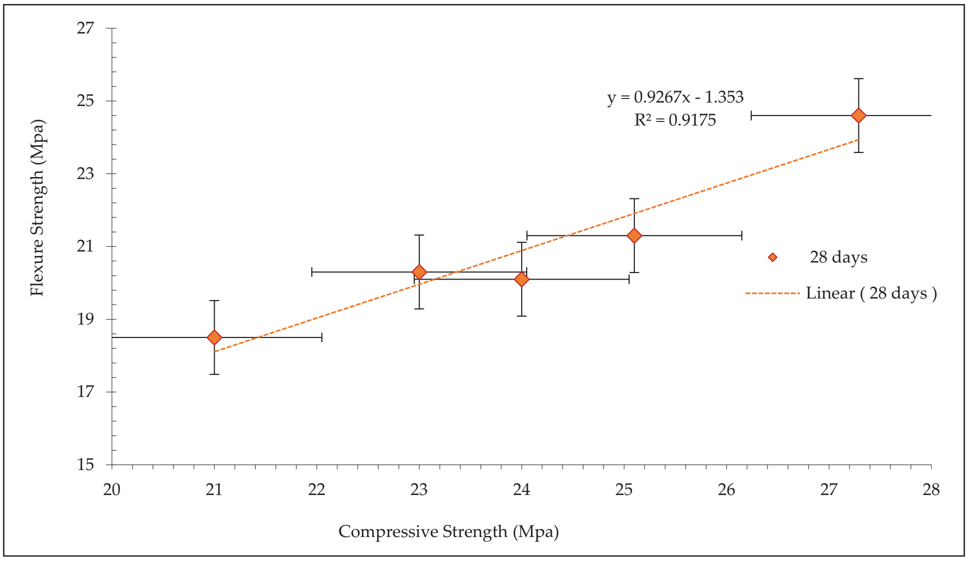

Figure 15. Correlation between compressive strength and flexure strength.

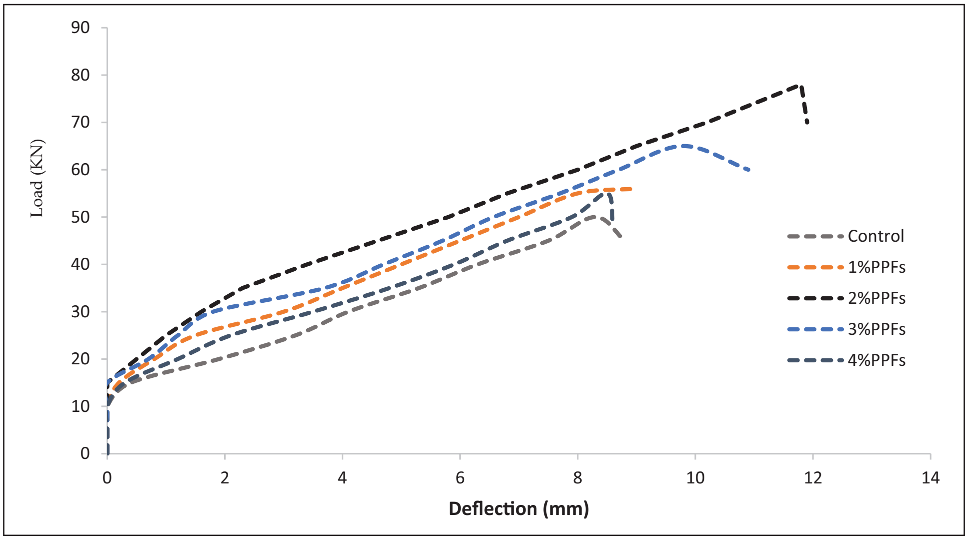

Figure 16. Load versus deflection.

the beams, the ductility factor can be introduced according to ACI 363,[50] which is the ratio between the deflection at the failure to the deflection at the yield point. As concrete is a brittle material that does not give any warning or deformation before failure which is not appealing for any construction material. The ductility index of varying dosages of PPFs were shown in Table 6. It can be observed that the ductile behavior of the beam can be considerably increased with the incorporation of PPFs having maximum ductility at 2.0% addition of PPFs which was almost 35% higher than from reference concrete. Also, the article reported that raise in fiber quantity will result in improved ductility, and strength.[24] Adding of PPFs in concrete enhances not only the strength attributes but also the ductility.[18]

Table 6. Ductility index.

Polypropylene fiber (%)	Deflection at yield point (mm)	Deflection at ultimate point (mm)	Ductility index
0	1.8	7.8	4.33
1	1.6	9.2	5.75
2	2.1	12.9	6.14
3	1.6	9.2	5.75
4	1.5	8.3	5.53

Crack patterns. The patterns of cracks were almost similar in all beam samples, the first crack developed at different levels of load with varying dosages of polypropylene fiber (PPFs). As the load is raised, vertical flexural cracks advance horizontally to the support from the mid-span as shown in Figure 17. It can be also noticed that flexure cracks reduced as the percentage of PPFs increased. It is due to fact that PPFs acts as cracks stopper which increased the tensile capacity of the beam. However, at a point of higher load, some additional cracks began to generate across the length of the sample, proliferating upward. Before the failure, compressive cracks began to form at the top surface of the concrete beams. Such compressive cracks increased with the incorporation of PPFs due to increase tensile capacity. Similar cracking behavior of beam with addition steel fibers was observed by Ahmad et al.[4]

First crack load. It is that load where the first signs of yielding on the side of the reinforced cement concrete (RCC) beam are observed which can be done visually during the test. Loads at first cracking from the experimental outcome were shown in Figure 18. It can be observed that strength at the first crack is raised with the addition of PPFs in comparison to the control concrete beam. The beam which contains 2% PPFs, first crack load about 80% higher than as in comparison to control. This is due to improvement in the concrete fraction bond because of PPFs and thus the consequent notable expansion of cracks. The strain capacity of concrete is increased due to the addition PPFs percentage, which leads to the greater load absorption capacity of concrete. Hence first crack load is increased. However, beyond the 2% addition of PPFs, the compaction process become more difficult due to decreased workability as discussed above which results in porous concrete, leading to decreased first crack load.

Figure 17. Crack pattern.

Maximum crack width. Figure 19 shows the results of maximum crack width with varying percentages of PPFs. Maximum crack widths of fiber reinforced concrete beams were calculated at the same level of load (50kN). As shown in Figure 18 that adding of PPFs causes an effective decrease in maximum crack width in fiber reinforced concrete (FRC) beams as in comparison to control concrete beams. When 2.0% PPFs were added, the maximum crack width was decreased by about 64%, as compared to control. This is because of the improvement in the bond of concrete elements when fibers were present in the matrix. The fibers delay the propagation of micro-cracks since fibers bridge these cracks and restrain their widening, thus improving the post-peak ductility and energy absorption capacity.[4]

Conclusions

In this paper, the effects of various polypropylene fibers dosage by weight of cement (0%, 1.0%, 2.0%, 3.0%, and 4.0%) are investigated on the performance of concrete. Based on experiment tests, the following conclusion has been drawn.

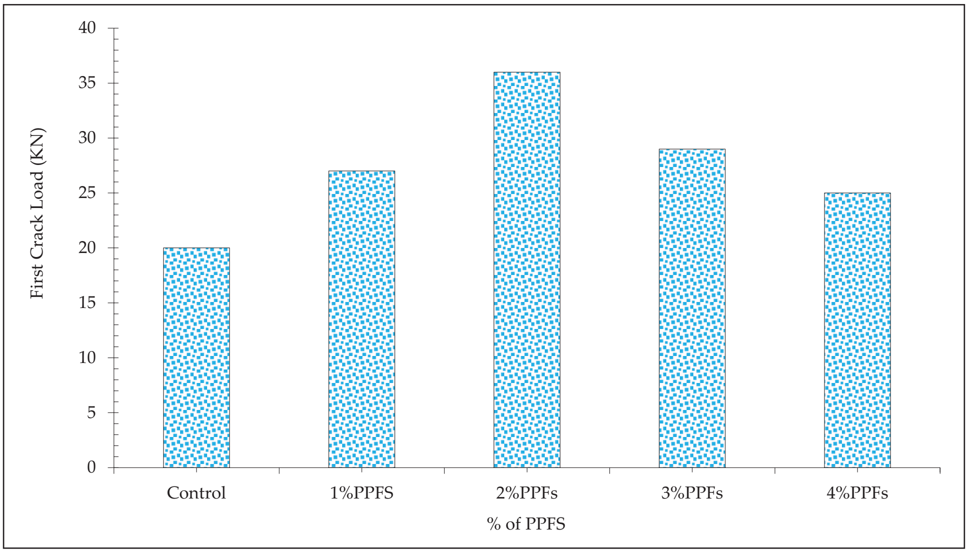

Figure 18. First crack load.

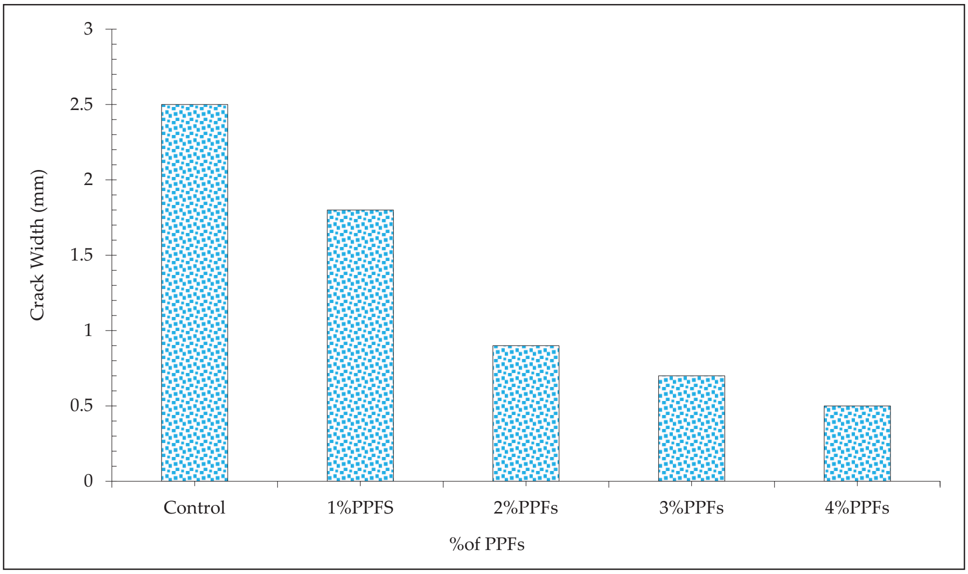

Figure 19. Crack width.

- The workability of concrete was reduced due to the incorporation of polypropylene fibers due to the larger surface area of fibers. The decrease in slump value is inside the scope of 20%–47% for various percentages of PPFs.
- Fresh density increased with the addition of polypropylene fibers up to 2.0% addition and then decrease having a maximum fresh density at 2.0% of PPFs which is 10% higher than reference concrete.
- The highest strength (Compressive, split tensile, and flexure strength) was obtained at a 2.0% dosage of polypropylene fiber. It is due to crack prevention of PPFs. At 28 days of curing, Compressive strength is 12% higher than reference concrete at 2.0% addition of PPFS
- Flexure and split tensile is about 23% and 12.5% higher than reference concrete at 2.0% addition of PPFs after 28 days of curing respectively.
- However, beyond 2.0% dosage strength was reduced due to lack of workability which results in more compaction efforts is required, leading to more pore in hardening concrete resulting in less strength. Therefore, a higher dose of superplasticizers is required for a higher dose of PPFs.
- Ductility index, first crack load, maximum crack width, and load-deflection inter-relations were considerably improved due to incorporations of PPFs. The ultimate load is about 23% higher than reference concrete. The maximum ductility index is 6.14 which is 41% more than reference concrete. It is due to fact that the tensile strain capacity of concrete was increased due to the addition PPFs fiber percentage, which leads to the greater load absorption capacity of concrete.

From this study, we can recognize that the addition of PPFs has considerably raised the strength as well as offset the undesirable brittle nature of concrete.

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