Comparison of Mechanical Properties of Normal & Polypropylene Fiber Reinforced Concrete

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Abstract

Concrete is the most commonly used construction material in the world. However, normal weight concrete shows less resistance to flexure. This research dealt with the technique to improve material efficiency in flexure as well as in compression, using polypropylene fibers. Different samples of concrete were prepared containing different dosages of polypropylene fibers (0.1%, 0.2%, 1% and 2% of the total concrete volume). The samples were then tested in compression and flexure, after 7, 14 and 28 days. The experimental investigation showed that the fibers increase the flexural strength of concrete in elastic range, when used in a specific limit. Maximum efficiency from the material was obtained at 0.2% dosage of fibers. Below and above this percentage the flexural and compressive strengths start decreasing. The experimental results also confirmed that with the gradual increase in polypropylene content the water absorption of concrete increases.

Keywords: *polypropylene fibers, flexure strength, compressive strength, shrinkage*

1. Introduction

Concrete is the most commonly used construction material. It is more advantageous to use in construction than any other construction material, i.e., steel, wood, lime etc. The use of concrete in the world is increasing day by day. Many mega projects and modern day civil engineering wonders are constructed from concrete. Due to the importance of concrete, a lot of research is being carried out in the world upon several types of concrete based on their strength, content and setting time. Researchers always consider different additives, plasticizers and admixtures to use in concrete in order to reduce cost, improve strength or to reduce final setting time. There are some materials which, when added to concrete, impart special properties to concrete. Some materials, when used in concrete, impart negative effects on its performance and hence it no longer remains suitable for use in construction.

On the other hand, there are some materials which are used in concrete to enhance the tensile strength of concrete. Since concrete has little tensile strength, and hence is liable to flexural cracks which subsequently result in the spalling of concrete leading to reduction in cross section of structural members and loss of aesthetics. Sometimes, this problem becomes so pronounced that it causes the collapse of one member, resulting in the failure of structure which can be hazardous for many lives. Researchers try to negotiate with this problem by adding certain materials in concrete to enhance its tensile and flexural strength. Steel is a material having high tensile strength and is used most commonly to cope with flexural and tensile stresses in concrete structures.

There is another technique to enhance the strength of concrete which is called fiber reinforcing of concrete. Fibers of different polymers are used to improve efficiency of the material in terms of strength and resistance against cracks. The problem encountered by the heavy dead loads imposed on the buildings along with the high cost of construction can be solved by the addition of saw dust in recommended amount as an admixture [1]. Mechanical properties of concrete can be improved by the addition of Shabath stone incrementally [2]. Polypropylene is one of those polymers which can be used for this purpose. It improves the mechanical properties of concrete during direct exposure to heat [3]. This material is easily available locally and is very useful because it allows concrete to improve its mechanical properties. Extensive research was carried out on the use of these fibers in concrete in different proportions and very useful results were obtained. Fibers of polypropylene are also used in order to improve shrinkage cracking of concrete [4]. Influence of type, length and diameter of fiber on the resistance against shrinkage cracking has been observed also. The longer the fiber the better will be the resistance against cracking. Similarly there was found inverse relationship between shrinkage & shrinkage [5]. Additionally, it also improves impact resistance of concrete when used in specific proportion [6]. Keeping in view at the uses of polypropylene against heat, in improving impact and shrinkage resistance, research work was carried out to check the material behavior in compression as well as in flexure. Since concrete has very less tensile strength, the aim was to check whether the use of polypropylene fibers also improves the flexural strength or not. The results were satisfactory and after experimentation it was observed that the fibers are equally good in improving flexural strength of concrete. But the behavior of material was not linear. It was observed that a specific limit (0.2% fibers to total concrete volume) was found to be efficient. The methodology of research is briefly explained under heading “Research Methodology”. Special care was taken of the limitations of shrinkage cracking as explained and concluded in literature [7].

Toughness and strength improvement in cement based matrices are achieved through the addition of Polypropylene micro fibers [8]. Various tests conducted on concrete structures showed that compressive, tensile and bending strength of concrete increases with fiber volume [9]. Polypropylene fibers have hydrophobic nature [10]. The presence of Polypropylene fibers does not require extra amount of water for concrete [11]. Recent developments have shown that by the addition of various polymeric materials in concrete the micro cracks inside the concrete matrix is reduced significantly [12]. Polypropylene fibers also reduce the surface bleeding and settlement cracks in concrete [13]. The addition of polymeric materials in concrete also reduces the shrinkage of matured concrete [14]. The increased reduction of the amount and size of micro cracks in Polypropylene fiber reinforced concrete improves its tensile strength. Polypropylene fiber has shown that it not only increases compressive, tensile and flexure strength [15] but also improves the impact resistance of concrete and the bond strength of concrete. Studies conducted on fibers also indicate that an increase in energy absorption under compression test can be achieved [16]. Studies have shown that the geometry, orientation and distribution of the fibers in concrete matrix also improve its mechanical properties [17].

A considerable amount of research has been done regarding the effects of the addition of polypropylene fiber and its effect on numerous properties. Akca did a study by addition of polypropylene fibers in recycled aggregate concrete and found out that optimum fiber content was 1% by volume [18]. Ramujee evaluated the strength of polypropylene fiber reinforced concrete and concluded that 1.5% by weight is optimum addition for best results [19]. Saadun performed dynamic impact load on polypropylene fiber reinforced concrete and found that the addition of fibers enhanced impact load capacity of concrete [20]. Ranjbar did a Comprehensive Study of the Polypropylene Fiber Reinforced Fly Ash Based geopolymer. The results showed that incorporation of PPF up to 3 wt % into the geopolymer paste reduced the shrinkage and enhanced the energy absorption of the composites [21].

This study illustrates the comprehensive experimental data based on the addition of Polypropylene fibers in concrete matrix. Various compressive and flexure tests have been performed to get the optimum dosage of fibers.

2. Material Properties

Materials used in this research work were cement, fine aggregates (sand), coarse aggregates, Polypropylene fibers and water. In this research work Ordinary Portland Cement (OPC) conforming ASTM C150 Type-I was utilized and its detailed physical properties are reproduced in table 1. Fine aggregates (Sand) conforming to ASTM C33 from Lawrencepur with specific gravity of 2.65 and fineness modulus of 2.65 was used. Coarse aggregates having maximum size of 20mm from Margalla conforming ASTM C33 was used in Concrete mix. Polypropylene fibers had length of 9mm – 12mm and density of 0.910 g/cm^3. Detailed physical properties of Polypropylene fibers are discussed in table 2. Concrete test specimens were cured according to ASTM C192.

2.1. Specimen and mixture details

Concrete specimens were tested for compressive strength and flexure strength at the age of 7 days, 14 days and 28 days. Target strength of concrete mix was 20 MPa and mix design ratio was 1:2.2:4.2 with water to cement ratio of 0.45 having slump value of 50mm. Polypropylene fibers in proportion of 0%, 0.1%, 0.2%, 1%, and 2% to total volume of concrete were added to normal concrete. Samples were cured according to ASTM C192 till the test day (figure 5). Cylinder specimens having size 150 mmϕ x 300 mm (6 in ϕ x 12 in) were casted for Normal Concrete and Fiber Reinforced Concrete for compressive strength test according to ASTM C 39. Prismatic section of concrete beams having size 100 mm x100 mm x 500 mm (4 x 4 x 20 in) were casted for Normal Concrete and Fiber Reinforced Concrete for flexural strength test according to ASTM C 78. Details of test specimens are given in table 3. Layout of research work is given in figure 1.

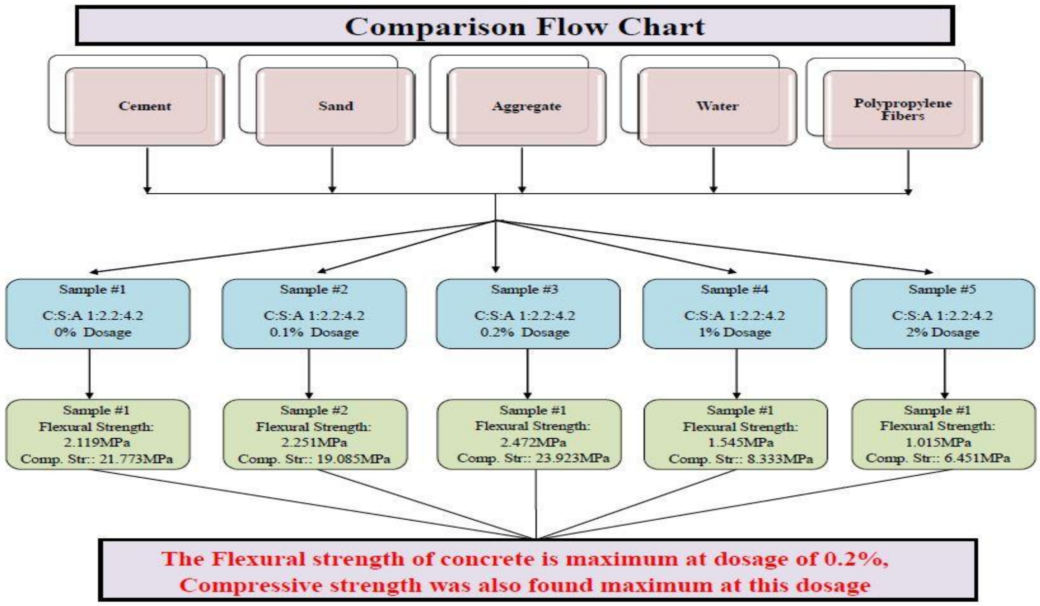

Figure 1: Layout of research work

2.2. Research Methodology

The objectives of this research are to compare the compressive strength, flexure strength and water absorption of Polypropylene fiber reinforced concrete with normal concrete. Concrete mix design conforming to ACI 211.1 was prepared. Compressive strength, flexure strength and water absorption was determined according to ASTM C39, ASTM 78 and ASTM 1585, respectively. Two samples were prepared for each test to determine average compressive strength, flexural strength and water absorption at various ages. The results for various dosages are compared among themselves and with concrete having no fibers.

Table 1: Physical properties of cement

Properties	Cement
Specific gravity	3.65
Specific surface area (m^2/Kg)	340
Normal Consistency (%)	29.3
Initial setting time (min)	103
Final setting time(min)	220

Table 2: Physical properties of polypropylene fibers

Properties	Description
Density (g/cm^3)	0.910
Fiber Length (mm)	9-12
Fiber Diameter (micron)	Approx 15-30
Water Absorption	Nil
Tensile strength (MPa)	300-450
Elongation at break (%)	>15
Softening point (^{o}C)	160-170
Specific Surface area (m^2/Kg)	Approx 200
Thermal conductivity	Low

Table 3: Details of Test Specimens

Specimen	Dimensions	No
1. Cylinder	150mm ϕ x300 mm	30
2.Prism	100mmx100mmx500mm	12

3. Results and Discussions

The ordinary plain cement concrete has its own specified value of compressive strength, flexural strength and water absorption depending upon the grade of concrete. But the addition of Polypropylene fibers to the reinforced concrete revealed the fact that both the compressive as well as flexural strength will increase if there is a specific dosage of fibers. Different tests (compressive strength, flexure strength and water absorption) were performed to make the comparison of properties between normal and fiber reinforced concrete.

3.1. Effect on Compressive Strength

In order to check the compressive strength, different specimens of cylinder were prepared by varying the dosage of Polypropylene fibers upto 0.1%, 0.2%, 1% and 2%. The compressive strength of the entire specimen was checked at various stages, i.e., after 7 days, 14 days and 28 days (figure 6) by using the Shimadzu Universal testing machine. After the detailed analysis of strength development considering the water absorption parameter, a specific dosage of Polypropylene fibers was concluded to give desired results. Table 4 shows the calculations regarding the average compressive strength achieved by the specimen. It is clear from the calculations that the dosage of 0.2% fibers to the reinforced concrete has its maximum average compressive strength after 7 days, i.e., 21.235 MPa. However, plain cement concrete has its compressive strength value equal to 15.590 MPa. Above or below the 0.2% dosage the observed compressive strength values were less. After 14 days, the maximum average compressive strength value was 22.579 at 0.2% dosage, which was again high as compared to the plain cement concrete compressive strength that was 19.891 MPa. It can be inferred from table 4 that the maximum average compressive strength of the cylinders at 0.2% dosage was 23.923 MPa after 28 days. Figure 2 and figure 3 give the comparison between the compressive strength and tensile strength of normal and fiber reinforced concrete at different stages.

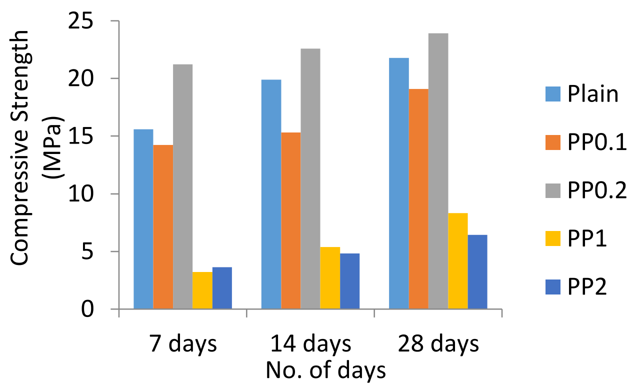

Figure 2: Graph showing comparison of compressive strength

Table 4: Comparison of compressive strength at various ages

Sr #	Sample designation	Type of specimen	Cross-section dimensions m x m	Cross-sectional area sq. m	Load kN	Compressive strength MPa	Avg. compressive strength MPa
1	PLD7	Cylinder	0.15 x 0.30	0.018	294.234	16.128	15.59
2	PLD7	Cylinder	0.15 x 0.30	0.018	274.6184	15.053	
3	PLD14	Cylinder	0.15 x 0.30	0.018	372.6964	20.429	19.891
4	PLD14	Cylinder	0.15 x 0.30	0.018	353.0808	19.353	
5	PLD28	Cylinder	0.15 x 0.30	0.018	392.312	21.504	21.773
6	PLD28	Cylinder	0.15 x 0.30	0.018	402.1198	22.041	
7	PP0.1D7	Cylinder	0.15 x 0.30	0.018	255.0028	13.978	14.246
8	PP0.1D7	Cylinder	0.15 x 0.30	0.018	264.8106	14.515	
9	PP0.1D14	Cylinder	0.15 x 0.30	0.018	235.3872	12.902	15.321

10	PP0.1D14	Cylinder	0.15 x 0.3(	0.018	323.6574	17.741	
11	PP0.1D28	Cylinder	0.15 x 0.3(	0.018	333.4652	18.278	19.085
12	PP0.1D28	Cylinder	0.15 x 0.3(	0.018	362.8886	19.891	
13	PP0.2D7	Cylinder	0.15 x 0.3(	0.018	382.5042	20.966	21.235
14	PP0.2D7	Cylinder	0.15 x 0.3(	0.018	392.312	21.504	
15	PP0.2D14	Cylinder	0.15 x 0.3(	0.018	421.7354	23.117	22.579
16	PP0.2D14	Cylinder	0.15 x 0.3(	0.018	402.1198	22.041	
17	PP0.2D28	Cylinder	0.15 x 0.3(	0.018	441.351	24.192	23.923
18	PP0.2D28	Cylinder	0.15 x 0.3(	0.018	431.5432	23.654	
19	PP1D7	Cylinder	0.15 x 0.3(	0.018	49.039	2.688	3.226
20	PP1D7	Cylinder	0.15 x 0.3(	0.018	68.6546	3.763	
21	PP1D14	Cylinder	0.15 x 0.3(	0.018	80.42396	4.408	5.376
22	PP1D14	Cylinder	0.15 x 0.3(	0.018	115.7320<	6.344	
23	PP1D28	Cylinder	0.15 x 0.3(	0.018	137.3092	7.526	8.333
24	PP1D28	Cylinder	0.15 x 0.3(	0.018	166.7326	9.139	
25	PP2D7	Cylinder	0.15 x 0.3(	0.018	68.6546	3.763	3.629
26	PP2D7	Cylinder	0.15 x 0.3(	0.018	63.7507	3.494	
27	PP2D14	Cylinder	0.15 x 0.3(	0.018	78.4624	4.301	4.838
28	PP2D14	Cylinder	0.15 x 0.3(	0.018	98.078	5.376	
29	PP2D28	Cylinder	0.15 x 0.3(	0.018	127.5014	6.989	6.451
30	PP2D28	Cylinder	0.15 x 0.3(	0.018	107.8858	5.914	

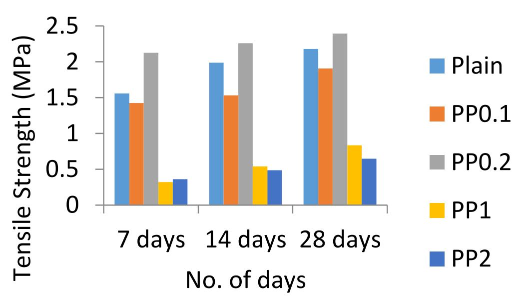

Figure 3: Graph showing Tensile strength

3.2. Effect on Flexural Strength

In order to check the flexural strength, different prisms were prepared by varying the dosage of polypropylene fiber and were tested at ages of 7 days, 14 days and 28 days respectively as shown in figure 3. Table 5 shows the calculations regarding the flexural strength of normal and fiber reinforced concrete at different stages. According to this table, the maximum flexural strength of prisms was obtained at

0.2% dosage equal to 1.964 MPa, 2.207 MPa and 2.472 MPa at age of 7 days, 14 days and 28 days, respectively. However, plain cement concrete prisms had less flexural strength as compared to fiber reinforced concrete equal to 1.766 MPa, 1.987 MPa and 2.119 MPa after 7, 14 and 28 days' time duration. Figure 7 depicts the comparison of flexural strength of normal and fiber reinforced concrete which shows that the flexural strength increases linearly up to 0.2% dosage but before and after that it decreases gradually. The maximum value of observed flexural strength was 2.472 MPa at 28 days age.

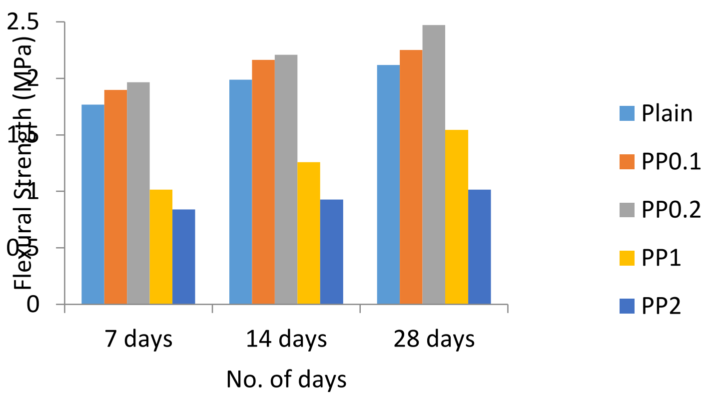

Figure 4: Graph showing Flexural strength

Table 5: Comparison of Flexural strength at various ages

Sr #	Sample designation	Cross-sectional area	Load		fr= 3Pa/bd^2
		sq. m	kg	N	(MPa)
1	PLD7	0.0103	400	3924	1.766
2	PLD14	0.0103	450	4414.5	1.987
3	PLD28	0.0103	480	4708.8	2.119
4	PP0.1D7	0.0103	430	4218.3	1.898
5	PP0.1D14	0.0103	490	4806.9	2.163
6	PP0.1D28	0.0103	510	5003.1	2.251
7	PP0.2D7	0.0103	445	4365.45	1.964
8	PP0.2D14	0.0103	500	4905	2.207
9	PP0.2D28	0.0103	560	5493.6	2.472
10	PP1D7	0.0103	230	2256.3	1.015

11	PP1D14	0.0103	285	2795.85	1.258
12	PP1D28	0.0103	350	3433.5	1.545
13	PP2D7	0.0103	190	1863.9	0.839
14	PP2D14	0.0103	210	2060.1	0.927
15	PP2D28	0.0103	230	2256.3	1.015

Where a=150mm, b=100mm and d=100mm

3.3. Effect on Water Absorption

From the test on water absorption, it was observed that increasing the percentage of polypropylene fibers also increases the water absorption directly as shown in table 6. According to this table the water absorption value for cylinders under 0.2% dosage is 4.223% after 7 days, 4.474% after 14 days and 4.966% after 28 days. Figure 4 gives the comparison for different values of fibers at different ages. According to this graph, water absorption value is high for maximum dosage of polypropylene fibers, i.e., for 2 % dosage. But at this percentage both compressive and flexure strength is reduced considerably. However below this percentage water absorption decreases linearly giving the optimum value at 0.2 % dosage. Figure 8 shows flexure strength test and graph in figure 5 shows the comparison of water absorption**.**

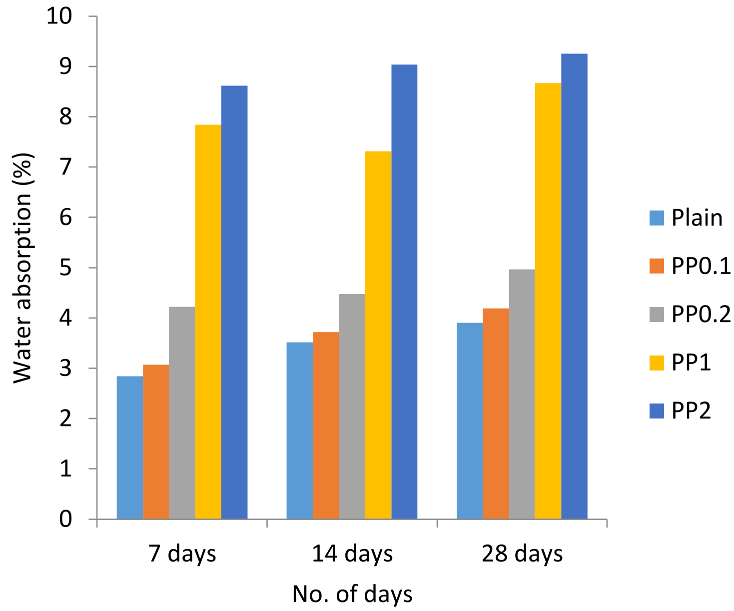

Figure 5: Graph showing comparison of water absorption

Figure 6: Samples after curing

Figure 7: Compressive strength tests of cylinders

Figure 8: Flexure strength test

Table 6: Comparison of water absorption at various stages

Sr #	Sample Designation	Type of specimen	Oven dried weight kg	Saturated Weight kg	Water Absorption %	Avg. Water Absorption %
1	PLD7	Cylinder	11.55	11.9	2.941	2.842
2	PLD7	Cylinder	11.7	12.03	2.743	
3	PLD14	Cylinder	12.223	12.67	3.528	3.516
4	PLD14	Cylinder	12.12	12.56	3.503	
5	PLD28	Cylinder	11.9	12.4	4.032	3.902
6	PLD28	Cylinder	12.5	12.99	3.772	
7	PP0.1D7	Cylinder	12.01	12.35	2.831	3.068
8	PP0.1D7	Cylinder	12.1	12.5	3.306	
9	PP0.1D14	Cylinder	11.95	12.32	3.096	3.718
10	PP0.1D14	Cylinder	11.98	12.5	4.341	
11	PP0.1D28	Cylinder	12.124	12.5	3.101	4.187
12	PP0.1D28	Cylinder	11.95	12.58	5.272	
13	PP0.2D7	Cylinder	11.6	12.15	4.741	4.223
14	PP0.2D7	Cylinder	11.957	12.4	3.705	
15	PP0.2D14	Cylinder	11.5	11.9	3.478	4.474
16	PP0.2D14	Cylinder	11.7	12.34	5.47	
17	PP0.2D28	Cylinder	11.45	12	4.803	4.966
18	PP0.2D28	Cylinder	11.7	12.3	5.128	
19	PP1D7	Cylinder	11.701	12.547	7.23	7.839
20	PP1D7	Cylinder	11.637	12.62	8.447	
21	PP1D14	Cylinder	12.087	12.9	6.726	7.311
22	PP1D14	Cylinder	12.234	13.2	7.896	
23	PP1D28	Cylinder	12	12.95	7.917	8.667
24	PP1D28	Cylinder	11.15	12.2	9.417	
25	PP2D7	Cylinder	11.18	12.25	9.571	8.617
26	PP2D7	Cylinder	11.3	12.166	7.664	
27	PP2D14	Cylinder	11.9	12.95	8.824	9.035
28	PP2D14	Cylinder	11.4	12.454	9.246	
29	PP2D28	Cylinder	11.67	12.7	8.826	9.254
30	PP2D28	Cylinder	11.67	12.8	9.683	

4. Conclusions

Following conclusions are drawn based on the experimental investigation:

1) Compressive strength was maximum at 0.2% Polypropylene dosage.
2) An increase in compressive strength of PFRC as compared to Normal concrete was found to be 8.93% at 0.2% Polypropylene fiber dosage.
3) Flexural strength was maximum at 0.2% Polypropylene dosage.
4) An increase in flexure strength of PFRC as compared to Normal concrete was found to be 14.27% at 0.2% Polypropylene fiber dosage.
5) Water absorption increased with increase in dosage of Polypropylene fibers.
6) The failure mode of concrete matrix depended on the fiber dosage and failure mode of PFRC was bulging in transverse direction.

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