

Structural Evolution of Fibre Reinforced Polymer (FRP) in reinforced concrete structures

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Abstract: Construction industry has always been in the market for the very long time. New methods of construction, technologies, machineries, materials, sustainable materials, etc keep coming up every now and then in the world. But the most extensively used material in the whole world is concrete. Concrete is a hard and brittle material which is made up of a mixture of Sand (fine aggregates), cement, Coarse aggregates and water. It has a very high compressive strength, but low tensile strength. When RCC structures are built, concrete performs the best when it is bonded with reinforcement. For this research Polypropylene fibres are used in M40 grade of Ready-Mix Concrete. With addition of PPF it is considered to be a useful method to increase the tensile strength of concrete and reduce cracks. Also, all the researchers suggest the use of PPF fibres to lower the risk of explosive spalling in high strength concrete and also to elevate temperatures. The paper deals with the additions of various proportion of PPF fibres in M40 high strength concrete mixes. A trail program was carried out to analyse the effects on compressive strength, tensile strength, flexural strength, water permeability test, RCPT under different curing conditions. The main aim of the investigation program is to study the effect of Polypropylene fibre mix by varying content such as 1%,1.5% & 2% and finding the optimum Polypropylene fibre content. Various tests such as Slump test, Compressive test, Split tension test, Flexural strength test, Permeability test of concrete, Water penetration tests IS carried out to see the effect of Polypropylene fibre on Ready mix concrete performance.

Index Terms: Concrete, Ready Mix Concrete, Fibre Reinforced Concrete, Polypropylene fibre, Compressive strength.

Abbreviations:

RCC: Reinforced Cement Concrete

RMC: Ready Mix Concrete

FRP: Fibre Reinforced Concrete

PPF: Polypropylene fibre

I. INTROCUITION

Concrete is a hard and brittle material which is made up of a mixture of Sand (fine aggregates), cement, Coarse aggregates and water. Concrete has a very high compressive strength and low tensile strength comparatively. Concrete has a good performance record with steel reinforcement, hence RCC structures are built. These RCC structures are subjected to cracks due to load, mix proportion not done well, compaction of concrete not done well during construction, or environmental changes. These cracks damage the structure, reduces the resistance power of the structure and can the structure can collapse as well due to water entering through the cracks and damaging the structure.

The change in concrete structures into permeable elements and consequently with high risk of corrosion is mainly due to cracks in it. Cracks not only affect the quality of the concrete and make it aesthetic improper but also makes the structure out of work but at the same time if the cracks do not exceed certain width, they do not damage the structure nor harm its accessibility. Thus, by adding PPF in the concrete the width of the cracks can be controlled so it can restrain the cracks from further opening. In order to achieve more deflection in the beam, additional forces and loads are required to pull out or fracture the fibres. This process helps in preserving the integrity of concrete and improving the load bearing capacity of the structural member beyond cracking. (M. Tamil Selvi¹*, 2013)

Polypropylene fibres (Fig: 1) are synthetic fibres which are obtained as a by-product from the textile industry. This are very cheap and available in different aspect ratio. The use of polypropylene reduces the plastic shrinkage cracking and

minimizes thermal cracking. It also provides reinforcement and protects concrete from damaging and prevents member beyond cracking. (Mohod1, 2015), (Yanzhu Liu, 2021)

In this research results of concrete performance on addition of polypropylene fibres with varying proportion is to be tested. Proportions with 1%, 1.5% and 2% in fresh concrete. Tests like slump test, compressive strength test, water permeability test, split and tensile strength test, flexural test, will be carried out to examine the effects on strength of concrete, its workability, modulus of elasticity. (Divya S Dharan1, 2016)



Figure 1: Polypropylene Fibre

II. OBJECTIVES

To study all the properties of fibre reinforced polymers and evaluate its properties on concrete. Compare the strength and durability of concrete made using Polypropylene fibre. To conduct various lab tests and understand how the strength of concrete can be enhanced by adding FRP

III. METHODOLOGY

For this research paper, methodology adopted was as such that RMC of M40 grade with fibre reinforced polymer in 1%, 1.5%, 2% ratio was casted in cubes and tested for following tests in a laboratory for 7, 28 and 45 days. Tests such as Slump test, Compressive test, Split tension test, Flexural strength test, Permeability test of concrete, Water penetration have been carried out to enhance the properties of concrete. These tests will help us understand the workability, strength and durability

of concrete when fibre reinforced polymer is added to Reinforced cement concrete. Following test procedure methodology is adopted in each test to conduct the analysis.

A. Slump Test

Slump test was conducted by using a slump cone of size which as 10 cm top diameter, 20 cm bottom diameter and height of 30 cm (Fig 2). Inside of cone to apply oil lubricant on all sides. Concrete mix to be filled (Fig 3) in the cone in 3 layers. After each layer 25 times taping of rod (Fig 4) after each layer. The Cone is now removed, concrete settles under its own weight and the vertical distance is to be measured. Difference of height of original level and new level after concrete settling is know as slump. From this test, slump value was measured for all the mixes.

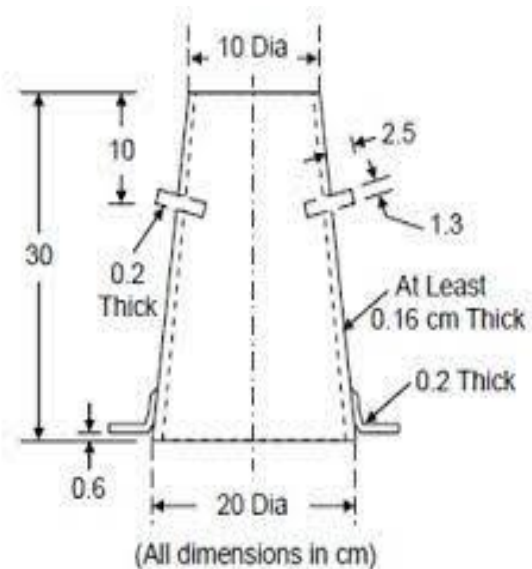


Figure 2: Slump cone



Figure 3: Slump Cone Test



Figure 4: Concrete taping

B. Compressive Strength Test

For this substantially 15cm * 15cm * 15cm cells are used in the following test. The procedure substantially includes first cleaning of the moulds duly and slicking from the inside (Fig 5). Also fill the concrete in the modulus roughly 50 mm thick and also compact it by using a tamping rod followed by levelling the face. After 16 to 72 hrs the moulds are removed and kept for curing in a water tank. Also place the cube in the machine in such a way that the load is applied to the opposite sides of the specimen. Rotate the portable portion gently so that it touches the top face of the cube. Apply a load of 140kg/cm²/min gradationally without shock. Till the instance fails and the record, the maximum load and note it. The same procedure is done for the specimens casted after days to get the maximum load and calculate the compressive strength of the concrete by dividing the load at failure by area of the specimen. (Fig 5, Fig 6, Fig 7)



Figure 5: Compressive Strength testing machine



Figure 6: Aggregate, cement, sand weighing in proportion



Figure 7: Cube casting

C. Split and Tensile Strength Test

One of the important properties of concrete is tensile strength as structural loads make concrete unsafe to tensile cracking. Since concrete is brittle and is weak intension and cause cracks therefore it is essential to conduct the tensile strength test on concrete. A sample id prepared in a cylinder of diameter 15cm and height 30cm. after the specimen is prepared and curing is done for 7,14,28 days use a marker and draw diametrical lines on the two ends of the specimen to verify that they are on the same axial place while measuring the dimensions of the specimen. Align the instance so that the lines marked on the ends are perpendicular and cantered over the bottom plate. Place the other plywood strip above the instance and bring down the upper plate touch the plywood strip. Apply the cargo continuously without shock at a rate of rough 9.9 ton/ nano second to 14.85 ton/ nano second and also note down the breaking cargo (P). (Fig 8, 9, 10,11)

Split tensile strength of concrete = 0.7 fck

The splitting tensile strength, $T_{sp} = 2P / \pi DL$

Where, P is the applied load

D is the diameter of the specimen

L is length of the specimen

Accordingly, $P=0.7fck * \pi dl/2$

Expected load = P x factor of safety

Splitting Tensile Strength:

$T_{sp}=2P/\pi DL$

where p here is the failure load.



Figure 8: Spilt and tensile machine

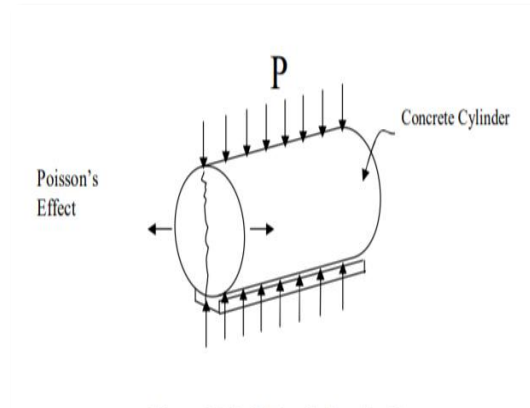


Figure 9: Load effect



Figure 10: Concrete mixing machine



Figure 11: Cube casting

D. Flexural Strength Test

This test shows us the ability of an unreinforced concrete beam or slab to withstand failure in bending. In this test a beam is casted in a mould of a size 15cm*15cm*70cm after the specimen is prepared it is kept in the flexural test machine which has two loading rollers with equally distributed load. The length of the rollers should not be less than 10 mm or more than the width of the test specimen. A total of four rollers shall be used, out of which three are capable of rotating along their own axes. The test specimen shall be placed in the centre of the machine correctly with the longitudinal axis of the cube at right angles to the rollers. The load applied should be at a rate of 400 kg/min for 15cm specimens. The Flexural Strength or modulus of rupture (f_b) is calculated by:

$$f_b = pl/bd^2$$

where:

“a” is the distance between the line of fracture and the nearer support, measured on the centre line.

d = failure point depth (cm)

p = max. Load (kg)

l = supported length (cm)

b = width of specimen (cm)



Figure 12: Flexural strength testing machine

E. Rapid Chloride Permeability Testing of Concrete

Chlorine attacks steel reinforcement, which leads to damage of structure hence RCPT test is carried out. In RCPT three cubes are casted in circular cylinder shape to fit it in the RCPT cell box (fig 15). Diameter of concrete is 100 mm and height are 50mm. Cylindrical concrete need some preparation before put in the cell. Water is added in beaker and boiled for one and a half hour. Then water to be allowed to be cooled at its own for 3 hours. Allow the 3 cylindrical bused to surface dry for 1 hour. Then in a deccicator put the 3 samples for 3 hours. Then add the cooled water in deccicator and give vacuum for 1 hour. Let the concrete samples soak in for 18 hours. Then remove the concrete and fit in the cell. Cylindrical concrete is fit in the cell, where one end it contains 3.0% Sodium Chloride and other end contains 3.0% Sodium Hydroxide solution (fig 13). A current voltage of 60 V DC Is passed through the RCPT test apparatus. After every 30 mins 60 Amp current for 6 hours and note the readings (fig 14).



Figure15: Cylindrical Concrete

F. Water Permeability test

Concrete cubes were casted for 28 days of size 150 * 150 * 150 mm. Cubes to be placed in water permeability test. Water was added in three columns. Pressure valve is opened, a pressure of 5kg /cm2. Maintain this pressure for 72 hours. Test sample to be removed, test sample will have water on surface. Then cube is kept in a compression machine, where pressure is applied and split into pieces. Water penetration depth should not be more than 25mm or else it will be considered as failed.

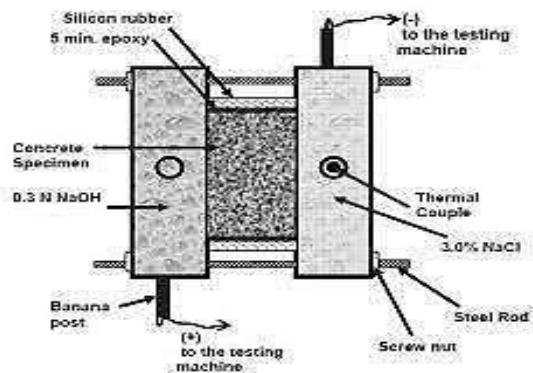


Figure 13: RCPT Cell

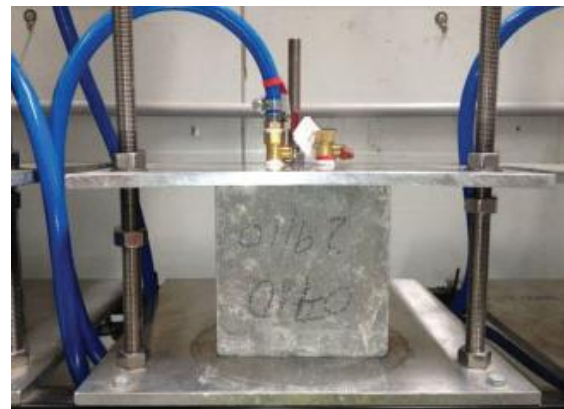


Figure 16: Cube Casting



Figure14: RCPT testing of concrete



Figure 17: Water Permeability test

IV. EXPERIMENTAL RESULTS AND DISCUSSION

Following are the results of various tests such as Slump test, Compressive test, Split tension test, Flexural strength test, Permeability test of concrete, XRD test, XRF test, Water penetration tests conducted to see the effect of Polypropylene fibre on Ready mix concrete performance when Fibre Reinforced polymer is added in 1%,1.5% & 2% proportion. The cubes were tested for 7, 14, 28 and 45 days for each test, but for this report test results up to 7 and 14 days are available only.

A. Slump Test

Following table shows results of Slump test with varying percentage of polypropylene in 1%, 1.5%, and 2% (Table 1)

Discussion: Below table and graph shows (Fig 18) test results of Slump test carried on M40 grade of Ready-mix Concrete. For 1% of Polypropylene fibre is concrete, as the cone was kept the initial slump collapsed, after 1 hour the height of slump cone was 200 mm, after 2 hours there was a drop of 20 mm and the height was 180 mm, and after 3 hours the cone height was dropped more to 145 mm. For 1.5 % of Polypropylene fibre is concrete, as the cone was kept the initial slump collapsed, after 1 hour the height of slump cone was 200 mm, after 2 hours there was a drop of 20 mm and the height was 180 mm, and after 3 hours the cone height was dropped more to 145 mm. For 2 % of Polypropylene fibre is concrete, as the cone was kept the initial slump collapsed, after 1 hour the height of slump cone was 200 mm, after 2 hours there was a drop of 20 mm and the height was 170 mm, and after 3 hours the cone height was dropped more to 150 mm. Hence it can be concluded that when percentage of polypropylene is increased to 2%, concrete performs better.

Trial Mixing Time	12:00 PM	3:30 PM	11:00 AM
PPF Percentage	For 1%	For 1.5 %	For 2%
Initial Slump	Collapse	Collapse	Collapse
After 01 Hour:	200 mm	200 mm	200 mm
After 02 Hour:	180 mm	180 mm	170 mm
After 03 Hour:	145 mm	145 mm	150 mm

Table 1: Slump test

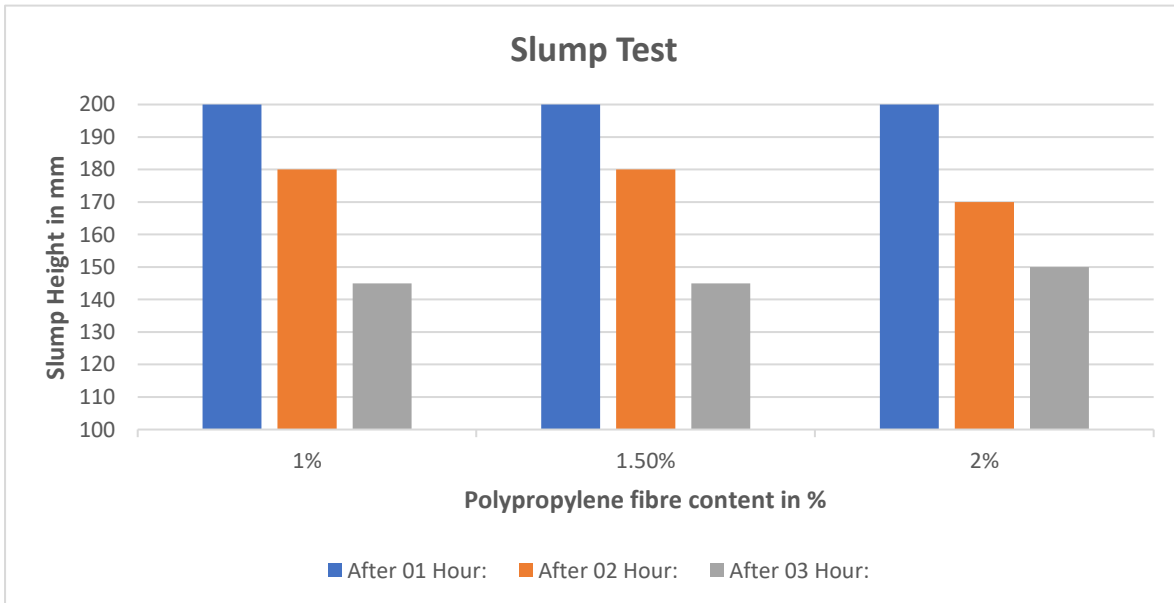


Figure 18: Graphical representation of Slump test

B. Compressive Strength Test

Following table shows results of Compressive strength test with percentage of polypropylene in 1 % (Table 2), 1.5%, 2% (Table 3):

Discussion: Below table and graph shows (fig 19) test results of compressive strength test carried on M40 grade of Ready-mix Concrete. Cubes were casted and tested on 7, 14 and 28 days. For 1% of polypropylene fibre, compressive strength of concrete on 7th day was 27.42 N/mm², on 14th days the strength increased to 40.49 N/mm² and on 28th day the strength was 51.63 N/mm².

For 1.5 % of polypropylene fibre, compressive strength of concrete on 7th day was 28.54 N/mm², on 14th days the strength increased to 41.24 N/mm² and on 28th day the strength was 52.34 N/mm². For 2 % of polypropylene fibre, compressive strength of concrete on 7th day was 29.12 N/mm², on 14th days the strength increased to 43.57 N/mm² and on 28th day the strength was 53.98 N/mm². Hence it can be concluded that when percentage of polypropylene is increased to 2%, concrete performs better.

Compressive Strength Test								
Concrete Grade: M 40				Cement + Pfa + Polyfibre				
Specimen Type: Cube				Specimen Size: 15cm x 15cm x 15cm				
Sr No	Age in 'Days;	Specimen No.	Weight in 'Kg'	Density (gm/cm3)	Corrected Load in 'KN'	Strength in 'N/mm2'	Avg Strength in 'N/mm2'	Remarks
1	7	1	8.425	2.50	617	27.42	27.42	
2	14	2	8.562	2.54	927	41.20		
		3	8.542	2.53	895	39.78	40.49	
3	28	4	8.513	2.52	1183	52.58	51.63	
		5	8.435	2.50	1154	51.29		
		6	8.720	2.58	1148	51.02		

Table 2: Compressive Strength Test for 1% PPF

Composition	Compressive Strength in N/mm2		
	7 Days	14 Days	28 Days
1.5 %	28.54	41.24	52.34
2 %	29.12	43.57	53.98

Table 3: Compressive strength test for 1.5% and 2%

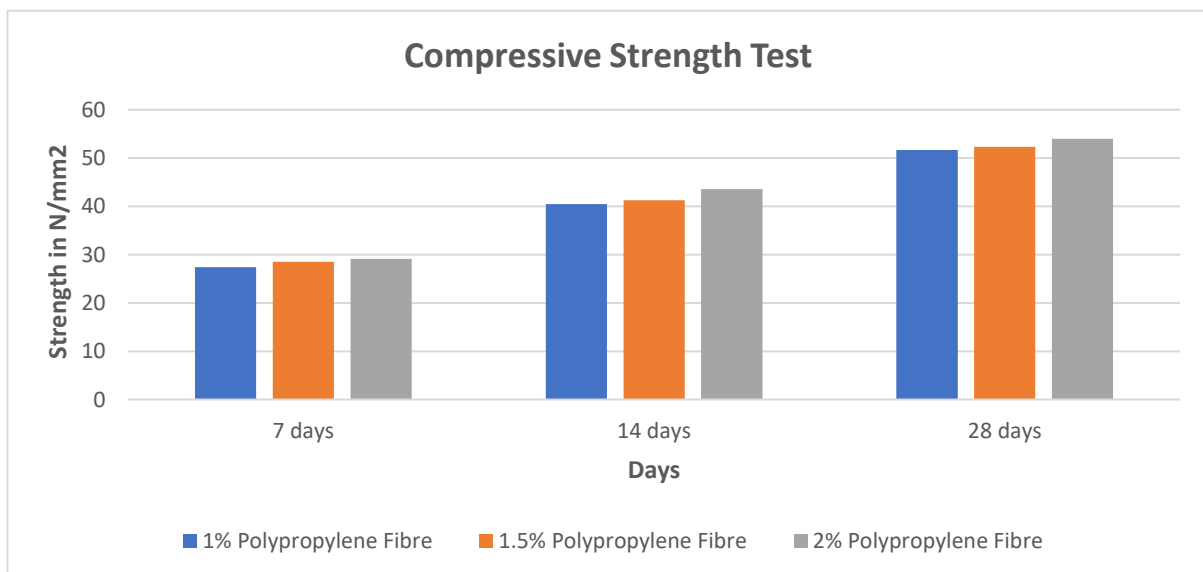


Figure 19: Graphical representation of compressive strength test

C. Split and Tensile Strength Test

Following table shows results of Split and Tensile strength test with percentage of polypropylene in 1 % (Table 4) 1.5%, 2% (Table 5):

Discussion: Below table and graph shows (Fig 20) test results of Split and tensile strength test carried on M40 grade of Ready-mix Concrete. Cubes were casted and tested on 7, 14 and 28 days. For 1% of polypropylene fibre, strength of concrete on 7th day was 3.42 N/mm², on 14th days the strength increased to 3.43 N/mm² and on 28th day the strength was 3.76 N/mm².

For 1.5 % of polypropylene fibre, strength of concrete on 7th day was 3.42 N/mm², on 14th days the strength increased to 3.45 N/mm² and on 28th day the strength was 3.76 N/mm². For 2 % of polypropylene fibre, compressive strength of concrete on 7th day was 3.44 N/mm², on 14th days the strength increased to 3.74 N/mm² and on 28th day the strength was 3.89 N/mm². Hence it can be concluded that when percentage of polypropylene is increased to 2%, concrete performs better.

Split and Tensile Strength Test								
Concrete Grade: M 40				Cement + Pfa + Polyfibre				
Specimen Type: Cube				Specimen Size: 15cm x 15cm x 15cm				
Sr No	Age in 'Days;	Specimen No.	Weight in 'Kg'	Density (gm/cm ³)	Corrected Load in 'KN'	Strength in 'N/mm ² '	Avg Strength in 'N/mm ² '	Remarks
1	7	1	8.597	2.52	655	3.42	3.42	
2	14	2	8.658	2.58	954	3.38	3.43	
		3	8.784	2.53	845	3.48		
3	28	4	8.754	3.02	985	3.54	3.76	
		5	8.758	3.12	1110	3.98		
		6	8.874	3.25	1245	3.76		

Table 4: Split and Tensile Strength Test for 1% PPF

Composition	Split and Tensile Strength in N/mm ²		
	7 Days	14 Days	28 Days
1.5 %	3.42	3.45	3.76
2 %	3.44	3.74	3.89

Table 5: Split and Tensile Strength Test for 1.5% and 2% PPF

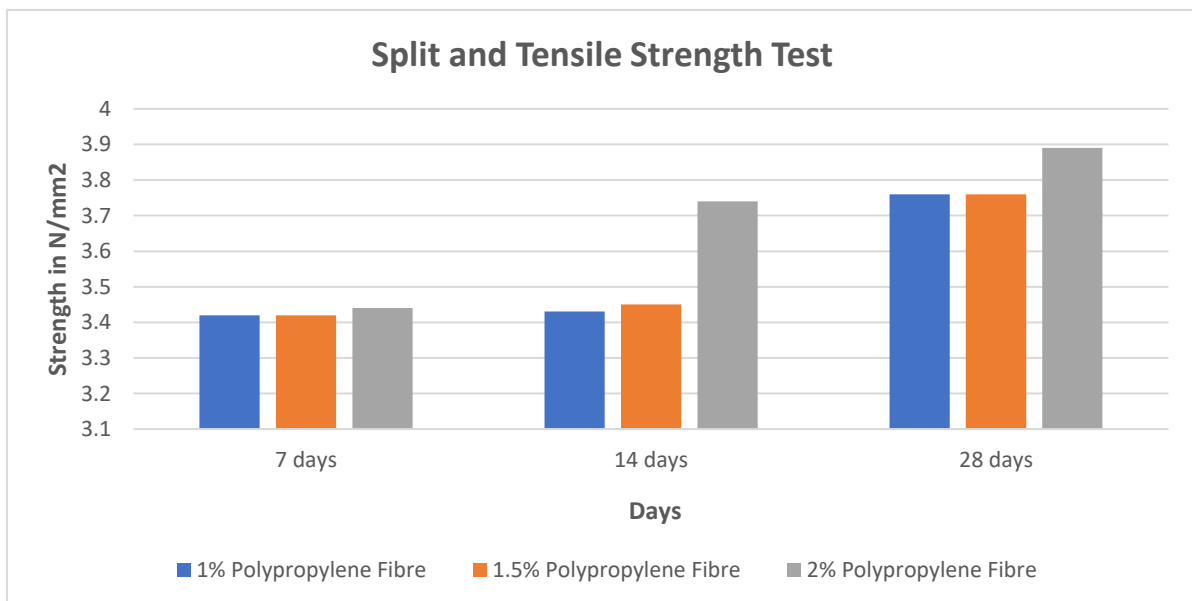


Figure 20: Graphical representation of split and tensile strength test

D. Flexural Strength Test

Following table shows results of Flexural strength test with percentage of polypropylene in 1 % (Table 6), 1.5% and 2% (Table 7):

Discussion: Below table and graph shows (Fig 21) test results of Flexural strength test carried on M40 grade of Ready-mix Concrete. Cubes were casted and tested on 7, 14 and 28 days. For 1% of polypropylene fibre, strength of concrete on 7th day was 4.89 N/mm², on 14th days the strength increased to 4.89 N/mm² and on 28th day the strength was 5.33 N/mm².

For 1.5 % of polypropylene fibre, strength of concrete on 7th day was 4.92 N/mm², on 14th days the strength increased to 4.92 N/mm² and on 28th day the strength was 5.4 N/mm². For 2 % of polypropylene fibre, compressive strength of concrete on 7th day was 4.94 N/mm², on 14th days the strength increased to 5.04 N/mm² and on 28th day the strength was 5.8 N/mm². Hence it can be concluded that when percentage of polypropylene is increased to 2%, concrete performs better.

Flexural Strength Test								
Concrete Grade: M 40				Cement + Pfa + Polyfibre				
Specimen Type: Beam				Specimen Size: 15cm x 15cm x 70cm				
Sr No	Age in 'Days;	Specimen No.	Effective Span	Load	Fracture Length (a Value)	Flexural Strength in 'N/mm ² '	Avg Strength in 'N/mm ² '	Remarks
1	7	1	600	30	185	4.88	4.89	
		2	600	28	192	4.78		
		3	600	32	196	4.65		
2	14	1	600	30	200	5.33	4.89	
		2	600	28	195	4.98		
		3	600	32	220	5.12		
3	28	1	600	30	195	5.33	5.33	
		2	600	28	245	4.98		
		3	600	32	230	5.69		

Table 6: Flexural Strength Test for 1 % PPF

Composition	Flexural Strength in N/mm ²		
	7 Days	14 Days	28 Days
1.5 %	4.92	4.92	5.4
2 %	4.95	5.04	5.8

Table 7: Flexural Strength Test for 1.5% and 2% PPF

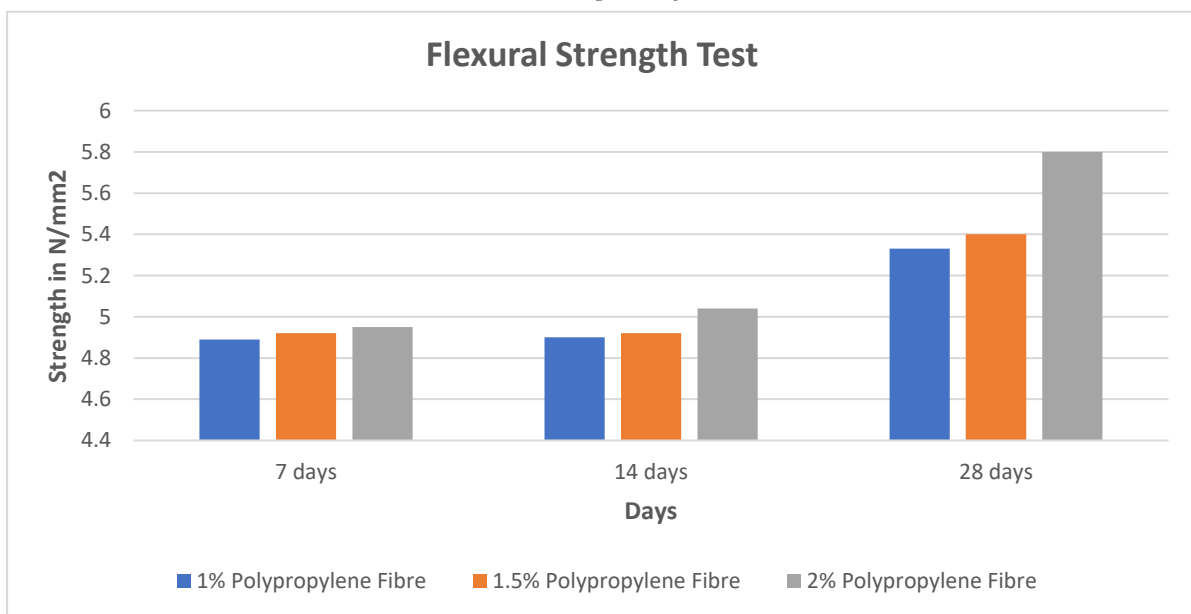


Figure 21: Graphical Representation of Flexural strength test

E. Rapid Chloride Permeability Test

Following table shows results of Rapid Chloride Permeability test with percentage of polypropylene in 1 % (Table 8), 1.5% and 2% (Table 9):

Discussion: Below table and graph shows (Fig 22) test results of RCPT test carried on M40 grade of Ready-mix Concrete. In Rapid chloride permeability test the 3 cylindrical cubes are tested in RCPT apparatus for 6 hours and result of those is shown in the table and graph.

As we can see in the table with 1% of polypropylene fibre in concrete the average result is 682.38 Coulombs whereas it is high for 1.5 % and 2% polypropylene fibre is 697.32 and 708.65 Coulombs. Penetrability more than 4000 is considered as high, between 4000 to 1000 is moderate and less than 1000 is low. Hence permeability of concrete is less for 1% of polypropylene fibre as compared to 1.5 % and 2% because in these cases penetrability of chlorine increases.

	Cell 1	Cell 2	Cell 3
Current in mA	25.9	24.6	31.8
Temperature in Degree C	25.8	27.8	27.4
Current in mA	27.0	25.5	30.4
Temperature in Degree C	26.5	28.3	27.9
Current in mA	27.3	26.4	32.5
Temperature in Degree C		29.1	28.7
Current in mA	29.1	27.4	32.5
Temperature in Degree C	28.4	30.0	30.4
Current in mA	30.2	29.8	34.2
Temperature in Degree C	29.7	31.7	31.3
Current in mA	30.8	29.8	34.9
Temperature in Degree C	29.7	33.0	32.1
Current in mA	32.7	30.7	34.9
Temperature in Degree C	31.6	33.0	32.1
Current in mA	33.5	3.0	35.5
Temperature in Degree C	32.4	33.8	32.9
Current in mA	33.8	31.9	36.6
Temperature in Degree C	32.9	35.6	33.7
Current in mA	33.9	32.5	37.3
Temperature in Degree C	33.1	34.4	34.2
Current in mA	34.3	33.0	37.7
Temperature in Degree C	33.4	34.7	34.2
Current in mA	34.5	33.2	38.2
Temperature in Degree C	33.6	35.1	34.2
RESULT	658.44 C	639.18 C	749.52 C
AVERAGE = 682.38 COULOMBS			

Table 8: RCPT Test for 1% PPF

Composition	Rapid Chloride Permeability in coulombs
1.5%	697.32
2%	708.65

Table 9: RCPT Test for 1.5% and 2% PPF

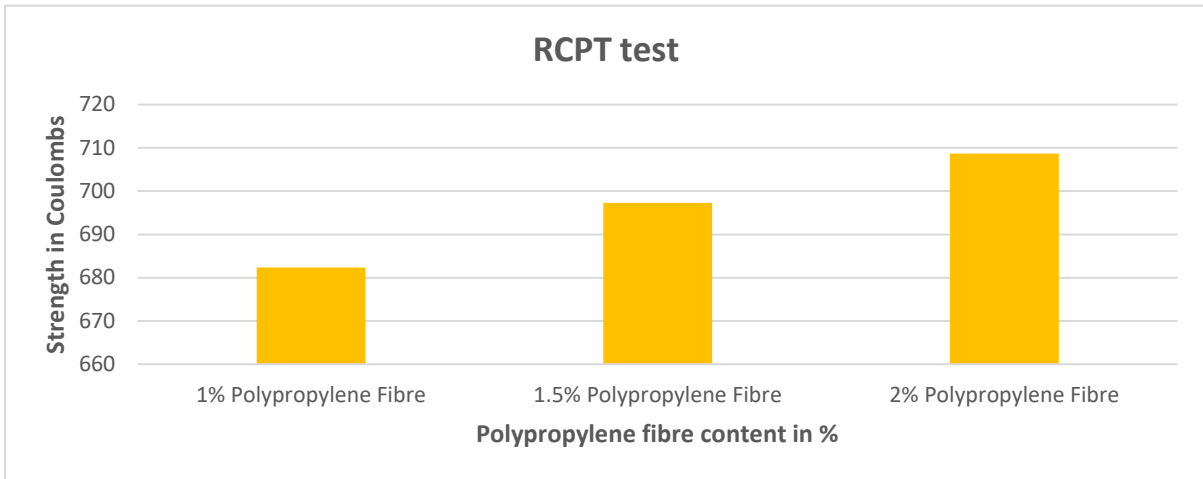


Figure 22: Graphical Representation of RCPT test

F. Water Permeability Test

Following table shows results Water Permeability Test of with percentage of polypropylene in 1 % (Table 10), 1.5% and 2% (Table 11):

Discussion: Below table and graph shows (Fig 23) test results of Flexural strength test carried on M40 grade of Ready-mix Concrete. In Water permeability test 3 cubes are casted with polypropylene in 1%, 1.5% and 2%.

As shown in table and graph, the results after 3 days of testing show that 1% polypropylene fibre has 2 mm and 4 mm water penetration. For 1.5%, water penetration is 2mm and 4mm. For 2.5%, water penetration is 1 mm and 4 mm. According to standard code water penetration should be less than 25mm. Hence in all cases water penetration is lees and it can be concluded that polypropylene fibre in concrete reduces water penetration in concrete.

Water Permeability Test							
Concrete Grade: M 40				Cement + Pfa + Polyfibre			
Specimen Type: Cube				Specimen Size: 15cm x 15cm x 15cm			
Sr No	Testing Start		Testing End		Depth of Penetration MM		Remarks
	Date	Time	Date	Time	Low	High	
1	21/8/22	2 pm	24/8/22	2 pm	2	4	
	21/8/22	2 pm	24/8/22	2 pm	2	3	
	21/8/22	2 pm	24/8/22	2 pm	1	5	

Table 10: Water Permeability Test for 1% PPF

Composition	Water Permeability Test (Depth of penetration in mm)	
	low	High
1.5%	2	5
2%	1	4

Table 11: Water Permeability Test for 1.5% and 2% PPF

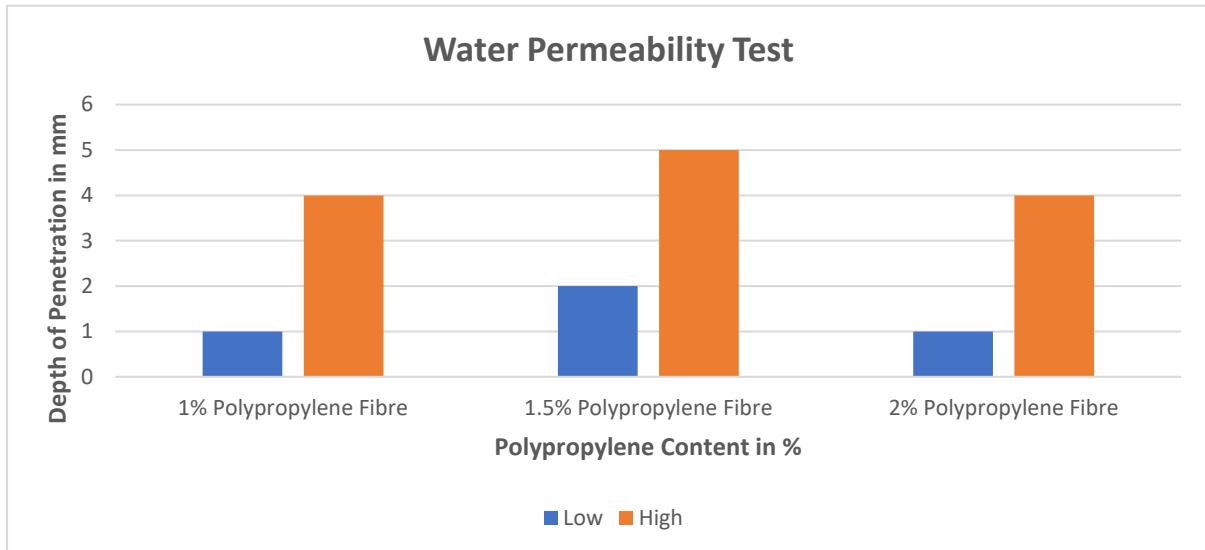


Figure 23: Graphical Representation of Water Permeability test

V. CONCLUSION

According to the experimental results, following are the results drawn. It can be said that use of Polypropylene fibre performs well in almost all the tests.

1. PPF reduces workability of concrete as fibres are added in concrete, slump value decreases. Hence accordingly if less workable concrete is needed then percentage of PPF can be 2% and if workability is needed more (i.e.) when concrete is pumped then PPF percentage to be kept 0.5%.

2. Compressive strength increases as the percentage of PPF increases and decreases after some time at 2%. Hence optimum percentage would be 1%.

3. In Split and Tensile strength test, strength increases with increase in percentage of PPF, but the increase in strength is not much. Its quite same for all. Hence optimum percentage would be 0.5%.

4. For Flexural strength test, it is same as for split and tensile strength test. Hence optimum percentage of PPF would be 0.5%.

5. For RCPT Test, permeability of concrete is less for 1% of polypropylene fibre as compared to 1.5 % and 2% because in these cases penetrability of chlorine increases. Hence optimum percentage of concrete is 1%.

6. For water permeability test, pertaining to standard code water penetration should be less than 25mm. Hence in all the PPF percentage content water penetration is less. Hence PPF in concrete reduces water penetration in concrete.

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