Comparative Analysis between Use of Polypropylene Fibers and Steel Fibers in Fiber Reinforced Concrete

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Abstract - *This research work explores the effect of fibers i.e. steel and polypropylene with nominal concrete. For this purpose, 35 specimens tested for each investigation of their physical properties like compressive strength, flexural strength and split tensile strength respectively. During olden days, only plain concrete were used and after that reinforced of steel concrete was introduced. In this work, the effects of steel and polypropylene fibers were observed after 28 days of casting. For this purpose, we kept the main focus on aspect ratios of fibers, orientation of fibers as well as quantities of fibers.*

After casting the specimen cubes were tested for compressive strength, cylindrical shaped specimens for flexural strength and beam shaped specimen for split tensile strength. The experimental results show that the hybridization of fibers has the slight impact on the compressive strength values, while it results to the increase in modulus of rupture (flexural strength), toughness (compressive strength) and impact resistance (tensile strength) values. The concrete with fibers reinforcement increased the strengths any all cases. At Some places the polypropylene fibers and somewhere steel fibers.

***Key Words*:** *fibers, steel fiber, polypropylene fiber, compressive strength, impact resistance*

1. INTRODUCTION

The most consumed man-made materials in construction field is concrete. It is the combination of cemetitious materials, water, aggregates and different kinds of admixtures in a particular ratio. Fresh concrete has a property of plasticity, which means before casting it behaves like plastic but as time goes, it gets hard like rock. These hardening properties happens due to chemical reactions between water and cement, it gets stronger with long time period.

Since the last century, the durability of RCC structures was primarily based upon the OPC round steel bars of mild steel, which was easily available in market. As time spent, these materials also changed with their physical appearance, properties and strength. For example, Pozzolana cement is used at the place of Ordinary cement and TMT bars are used at the place of mild steel bars.

The methods for checking strengths are based upon Indian Standards. Testing Machines gives the perfect results after investigation of cubes, cylinders and beams, which casted and kept in water for curing for 28 days continuously.

1.1 FIBER REINFORCED CONCRETE

For FRC, steel, glass fiber, synthetic and natural fibers can be used. For research purpose, here only steel and polypropylene is considered. Since, they are most common used type of fibers. The properties of concrete gets improve by mixing of fibers. The properties of concrete are durability, flexural strength, toughness, impact resistance and compressive strength. The physical improvement depends on the fiber type, size, configuration and fibers amount.

1.1.1 STEEL FIBER REINFORCED CONCRETE

SFRC is a combination of concrete and steel fibers. It may be placed by using same equipments of mixing and placing used as for conventional concrete. If we talk about the use of steel fibers at higher temperature, some applications up to 815^{o}C for elements from one side only are available. Stainless Steel fibers may also be used for production of refractory concrete. Steel fibers can improve strength of structure, decrease the steel reinforcement requirements., improve ductility.

1.1.2 POLYPROPYLENE FIBER REINFORCED CONCRETE

Polypropylene fibers are used in structural applications up to the maximum level since 1950 and recently in the pavement formation of roads. The availability of polypropylene is in the two forms that are film fibers and monofilament fibers. Production of monofilament fibers possible by the process by using the orifices in the spinner jet and then cut them in desired length. This film may be stretchable into tapes axially. These tapes are stretched over carefully over design roller pin systems which generates longitudinal cutting and these may be cut or twisted to produce the different types of fibrillated fibers. The fibrillated fiber contains a net-like formation structure. The tensile strength of fibers may be formed by the use of some molecular which is orientation obtained during extrusion process.

The Polypropylene has melting point of 165°C and can resist the temperatures up to about 100 ± 5°C for short time period before softening. This is inert material in nature and any chemical which may damage to polypropylene fibers, will be highly harmful to concrete mix. The polypropylene fibers are capable to resist the degradation by ultraviolet radiations or oxygen. However, in concrete after mixing with fibers, these remedies can be eliminated.

Polypropylene fibers can:

- Improve impact resistance.
- Improve mix quality over long time.
- Improve resistance towards explosive spalling if fire ceases.
- Reduce requirement of steel reinforcement.
- Improve ductility.

This fiber reinforcement has a great capacity of development in construction field. In future, these can make with traditional reinforcements to reduce the quantity of various materials or remove fully the reinforcements of steel etc. the main reason for not using the FRC is only that today there is not any design guidelines and FRC structures are costly too specially in case of building design. But for road design and all ground construction work gets improvement in their strength by using fiber reinforced concrete. There is no special man power required when we use the FRC because the cost of any construction increases maximum due to man power.

The fiber reinforcement can be used in different forms just like randomly distribution over the length of the structural member. The benefit of this addition is the increase in the value of shear resistance, which further controls crack. In addition to this, the fiber reinforced concrete can also be used in the form of tensile member to balance the steel reinforcement if oriented dimensionally.

1.2 RESEARCH OBJECTIVES:

The main objectives of the present research work are to evaluate and compare the followings:

- Conventional concrete strengths at normal temperature and pressure.
- Comparison of the strength of conventional plain cement concrete to the steel fiber reinforced concrete.
- Comparison between the strength of the conventional plain cement concrete with the polypropylene fiber reinforced concrete.
- Comparison of strengths of both steel and polypropylene fiber reinforced concrete with each other.
- Statistical techniques which are useful to compare for analytical interpretation of strengths for all i.e. conventional concrete and both FRCs.

1.3 METHODOLOGY

The fiber reinforcement efficiency may be examined based on two criteria i.e., strength enhancement, and toughness enhancement of the composite, compared with the brittle matrix.” To investigate the influence of various fibers and their volume fractions in concrete matrix, two types of fiber “steel fiber” and “polypropylene fiber”, were used. According to the purpose of present research, the optimum mix design achieved by M40 which was taken as reference for concrete mixes.

2.1 MIX DESIGN CONSIDERATION

Since the purpose of the study was to investigate the performance characteristic of FRC, seven different combinations were considered. In each combination, the proportions of cement content, fine and coarse aggregate, water, admixture were kept constant, while the corresponding fiber proportion by volume of concrete mix were different as 1%, 2% and 3%.

2.2 CASTING AND CURING

According to goal of this study and related tests, the following specimens were cast from each mix:

1. For evaluation of compression test: 5 Cubes for each with size of 150 x 150 x 150 mm with mixing of 0%, 1%, 2% and 3% by volume of concrete for

conventional concrete, steel and polypropylene fibers respectively.

2. For evaluation of flexural test: 5 beams for each mix with size of 100 × 100 × 500 mm with mixing of 0%, 1%, 2% and 3% by volume of concrete for conventional concrete, steel and polypropylene fibers respectively.
3. For evaluation of impact resistance test: 5 cylinders of each mix with size of 150 × 600 mm with mixing of 0%, 1%, 2% and 3% by volume of concrete for conventional concrete, steel and polypropylene fibers respectively.
4. After preparing the moulds concrete was placed in two layers vibrated with 50 Hz frequency leading to proper consolidation and concrete compaction. The curing of specimen in the fog room takes place having temperature range between 22° C – 24° C. The samples were extruded and cured in temperature in controlled water tank for 28 days.

2.3 TESTING

In this research, all tests were conducted in accordance with the relevant ASTM and Indian standards.

3. MATERIALS USED

3.1 CEMENT

For the experiment OPC – 53 grade is used. The different properties of the cement are shown below:

1. Fineness – 340 m^2/kg
2. Specific gravity- 2.96
3. Initial setting time - 90 min
4. Final setting time – 190 min

3.2 Fine aggregate:

For this study, the Zone-II sand (Mahanadi river (situated in Raipur,Chattisgarh-India) was used, over which the sieve analysis is performed using the various sieve sizes IS 10mm, IS 4.75mm, IS 2.36mm, IS 1.18mm, IS 600µ, IS 300µ, IS 150µ) based on IS 383:1963. Some important properties of fine aggregates are in Table 1

Table 1: Properties of Fine Aggregates

Properties	Results Obtained
Specific Gravity	2.65
Water absorption	0.65%
Fineness Modulus	2.48

3.3 COARSE AGGREGATE

20 mm as the maximum size of coarse aggregate was considered. The IS 383:1970 has been used to calculate the mix proportion of coarse aggregate, with IS 10 mm sieve size as 60% and with IS 20 mm sieve size as 40%. The properties of coarse aggregates are presented in Table 2.

Table 2: Properties of Coarse Aggregates

Properties	Results Obtained
Specific Gravity	2.67
Water absorption	0.61%
Fineness Modulus	4.01

Fibers: In this project work, Steel & Polypropylene fiber was used. In different weight fraction (0%, 1%, 2%, 3%) to concrete it was used.

4. RESULTS AND DISCUSSIONS

4.1 STRENGTHS OF SPECIMENS

Table 3 presents the compressive strengths for Nominal Mix:

Table 3: Compressive Strength for Nominal Mix

Compressive Strength(N/Sqmm) of 0% Fiber Grade M40		
	Observed C.S.	Avg. C.S.
Sample M1	37.4	38.78
Sample M2	36.8	
Sample M3	38.1	
Sample M4	40.8	
Sample M5	41.1	

Five samples of conventional concrete have taken for testing. The compressive strength of all cube samples given in the above table. When no fibers added in concrete, the strengths came accordingly and related to 40MPa after 28 days. Table 4 is showing compressive strength for steel fiber with mix of conventional concrete.

Table 4: Compressive Strength for Steel Fiber Mix

Compressive strength(N/sqmm) of 1%, 2% and 3% Steel Fiber Grade M40							
Aspect Ratio		**1%**	**Avg.**	**2%**	**Avg.**	**3%**	**Avg.**
50	Sample CS1.1	52.2	52.74	53.1	54.34	55.6	55.66
	Sample CS1.2	54.8		54.8		55	
	Sample CS1.3	53.2		54		54	
	Sample CS1.4	52.5		55		57.5	
	Sample CS1.5	50.9		54.8		56.2	
60	Sample CS2.1	53.3	53.4	54.8	56.94	56	58.12
	Sample CS2.2	52.1		54.5		55.8	
	Sample CS2.3	54.4		58		58	
	Sample CS2.4	55.1		58		60.2	
	Sample CS2.5	52.1		59.4		60.6	

For different aspect ratios i.e. 50 and 60, with mixing of 1%, 2% and 3% steel fibers added. The results found were more compressive strength as compared with conventional concrete. For more steel fiber mixing (3%), more strength observed on aspect ratio 60 whereas in case of minimum percentage of steel fiber i.e. 1%, compressive strength minimum compressive strength 52.74MPa came out. Table 5 is telling about the compressive strength of polypropylene fiber mix reinforced concrete.

Table 5: Compressive Strength for Polypropylene fiber Mix

Compressive strength(N/sqmm) of 1%, 2% and 3% Polypropylene Fiber Grade M40							
Aspect Ratio		**1 %**	**Avg.**	**2 %**	**Avg.**	**3 %**	**Avg.**
50	Sample CP1.1	38.8	41.32	48.8	47.02	49.4	49.2
	Sample CP1.2	40.4		44.4		50.8	
	Sample CP1.3	41.5		49.5		43.5	
	Sample CP1.4	42.4		44		57.8	
	Sample CP1.5	43.5		48.4		44.5	
60	Sample CP2.1	40.5	45.28	44.8	50.98	49.4	54.48
	Sample CP2.2	45.5		50.4		45.4	
	Sample CP2.3	48.9		53.6		60.1	
	Sample CP2.4	43.5		52.2		55.4	
	Sample CP2.5	48		53.9		62.1	

30 samples have been taken for polypropylene fiber mixes. Five samples of each percentage taken out. When 1% of polypropylene fiber added, 41.32MPa compressive strength got on Compressive Testing Machine for aspect ratio 50. Similarly for aspect ratio 60, compressive strength 45.28MPa measured. Table 6 presented to show the flexural strength of nominal mix.

Table 6: Flexural Strength for Nominal Mix

Flexural Strength(N/Sqmm) of 0% Fiber Grade M40		
	Observed F.S.	Avg. F.S.
Sample MF1	7.4	7.62
Sample MF2	7.8	
Sample MF3	7	
Sample MF4	7.8	
Sample MF5	8.1	

For M40 Grade of concrete, 5 samples have been taken. The observed flexural strengths were approximately to achieve target strength. So, the average flexural strength of all observed strength is 7.62MPa. Table 7 having Flexural strength for steel reinforced concrete mix.

Table 7: Flexural Strength for Steel fiber Mix

Flexural strength(N/sqmm) of 1%, 2% and 3% Steel Fiber Grade M40							
Aspect Ratio		**1 %**	**Avg.**	**2%**	**Avg.**	**3%**	**Avg.**
50	Sample FS1.1	8.9	8.54	8.5	9.18	10.5	10.62
	Sample FS1.2	8.1		8.4		10.2	
	Sample FS1.3	9.1		9.4		11.2	
	Sample FS1.4	8.4		9.8		11.4	
	Sample FS1.5	8.2		9.8		9.8	
60	Sample FS2.1	8	8.58	8.9	9.622	11.5	11.54
	Sample FS2.2	8.2		9.5		9.4	
	Sample FS2.3	8.1		9.4		12	
	Sample FS2.4	9.2		10.2		12.4	
	Sample FS2.5	9.4		10.11		12.4	

As similar to compressive strength, here again 30 samples collected and measured their respective strengths with 1%, 2% and 3% steel fibers by volume. The flexural strength for steel fibers is more than conventional concrete flexural strength. Table 8 is showing results after 28 days of flexural strength for polypropylene fiber mix.

Table 8: Flexural Strength for Polypropylene fiber Mix

Flexural strength(N/sqmm) of 1%, 2% and 3% Polypropylene Fiber Grade M40							
Aspect Ratio		**1 %**	**Avg.**	**2 %**	**Avg.**	**3 %**	**Avg.**
50	Sample FP1.1	36.5	37.76	39.5	39.18	40.1	41.4
	Sample FP1.2	36.5		37.8		40.5	
	Sample FP1.3	40		38.4		42.7	
	Sample FP1.4	38.2		40		41.8	
	Sample FP1.5	37.6		40.2		41.9	
60	Sample FP2.1	40.5	40.14	39	42.18	32.8	44.26
	Sample FP2.2	42.5		45.5		34.9	
	Sample FP2.3	36.4		40		50.8	
	Sample FP2.4	40.2		43.2		51	
	Sample FP2.5	41.1		43.2		51.8	

Here, after mixing of polypropylene fibers with conventional concrete, the flexural strengths are higher than steel fibers. If we talk about 1% addition of polypropylene fibers, we achieved 37.76MPa flexural strength for aspect ratio 50. Similarly, for aspect ratio 60, this value is 40.14MPa. Whereas for same aspect ratio, 44.26MPa at 3% addition of polypropylene fibers. Table 9 is presenting the split tensile strength after 28 days for conventional concrete.

Table 9: Split Tensile Strength for Nominal Mix

Spit Tensile Strength(N/Sqmm) of 0% Fiber Grade M40		
	Observed F.S.	Avg. F.S.
Sample MT1	2.9	3.56
Sample MT2	3.1	
Sample MT3	3.4	
Sample MT4	4.2	
Sample MT5	4.2	

For split tensile strength, cylinders were casted and tested in Compression Testing Machine after 28 days. The minimum and maximum values of split tensile strength were noted 2.9MPa and 4.2MPa respectively. Split tensile strength for steel fiber with different percentages is presented in Table 10.

Table 10: Split Tensile Strength for Steel Fiber Mix

Split Tensile strength(N/sqmm) of 1%, 2% and 3% Steel Fiber Grade M40							
Aspect Ratio		**1 %**	**Avg.**	**2 %**	**Avg.**	**3 %**	**Avg.**
50	Sample TS1.1	3.2	3.26	4.1	4.36	5.2	5.16
	Sample TS1.2	3		4.1		4.2	
	Sample TS1.3	2.9		4.3		5.4	
	Sample TS1.4	3.4		4.2		5.4	
	Sample TS1.5	3.8		5.1		5.6	
60	Sample TS2.1	2.9	3.36	6	4.76	4.5	5.28
	Sample TS2.2	3.2		3.5		5.6	
	Sample TS2.3	3.1		3.5		5.8	
	Sample TS2.4	3.4		5.2		5.9	
	Sample TS2.5	4.2		5.6		4.6	

In case of steel fiber addition, 5 samples of aspect ratio 50 with 1%, given 3.26MPa average split tensile strength, for 2% the average strength is 4.36MPa and for 3% the average strength is 5.16MPa whereas for aspect ratio 60 with 1% steel fibers, the average strength is 3.36MPa and with 2% fibers, average strength is 4.76MPa and the maximum strength is 5.28MPa with 3% addition of steel fibers. These values show that the split tensile strength of steel fibers is more durable than conventional concrete. Table 11 is presenting the split tensile strength of polypropylene reinforced concrete after 28 days.

Table 11: Split Tensile Strength for Polypropylene fiber Mix

Split Tensile strength(N/sqmm) of 1%, 2% and 3% Polypropylene Fiber Grade M40							
Aspect Ratio		**1 %**	**Avg.**	**2 %**	**Avg.**	**3 %**	**Avg.**
50	Sample TP1.1	4.2	4.16	4.5	5.3	5.1	5.76
	Sample TP1.2	2.4		4.5		5.1	
	Sample TP1.3	4.5		5.6		5.2	
	Sample TP1.4	4.5		5.8		6.2	
	Sample TP1.5	5.2		6.1		7.2	
60	Sample TP2.1	4.8	5.5	4.8	5.98	4.6	6.58
	Sample TP2.2	5.1		5.2		8	
	Sample TP2.3	5.6		6.2		6.1	
	Sample TP2.4	5.8		6.4		6.8	
	Sample TP2.5	6.2		7.3		7.4	

If we compare the strengths of both steel and polypropylene fibers with conventional concrete, we get polypropylene fibers shows maximum split tensile strength. At 1% polypropylene fiber mixing with conventional concrete, the average value is 4.16MPa, and for 2% and 3%, 5.3MPa and 5.76MPa respectively for aspect ratio 50. For aspect ratio 60 and 1% mixing of polypropylene fibers, the strength is 5.5MPa, 2% mixing of polypropylene fibers, the strength is 5.98MPa and lastly, for 3% mixing of polypropylene fibers, the strength is 6.58MPa.

4.2 COMPARISON BETWEEN STRENGTHS AT DIFFERENT ASPECT RATIO

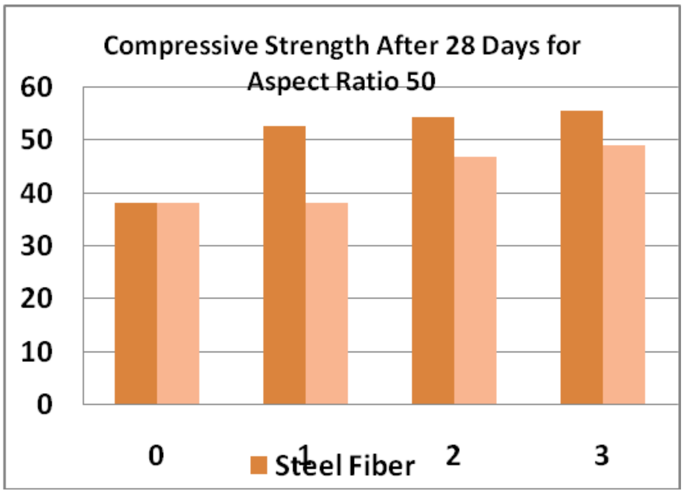

Figure 1: Compressive strength after 28 days for Aspect Ratio 50

Figure 1 is showing the compressive strength results after 28 days. After addition of steel fibers, compressive strength values increases as compared to polypropylene fibers. After addition of fibers with 1%, 2% and 3% small changes are coming in steel fiber whereas in case of polypropylene fiber, maximum changes are coming after 1% to 2%. In case of 2% and 3% polypropylene addition, a small change is there. If we compare between steel fiber and polypropylene fiber at 1%, 27% of total strength increased on addition of steel fiber.

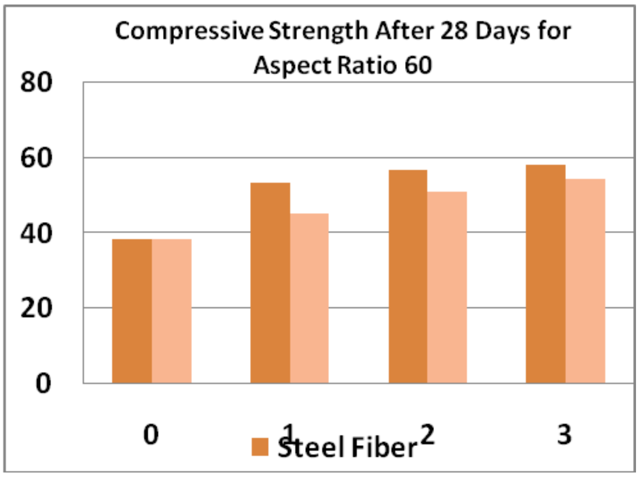

Figure 2: Compressive strength after 28 days for aspect ratio 60

Figure 2 is comparison between compressive strength results after 28 days for aspect ratio 60. For steel fibers, changes are very slow as compared to polypropylene fibers. On addition of 1% steel fiber, strength increased with 28% whereas in case of polypropylene fiber, strength increased 15% for same percentage. If we compare the changes in 1% to 2%, the strength gained approximately 6% for steel fibers and for polypropylene fiber, it is 11%.

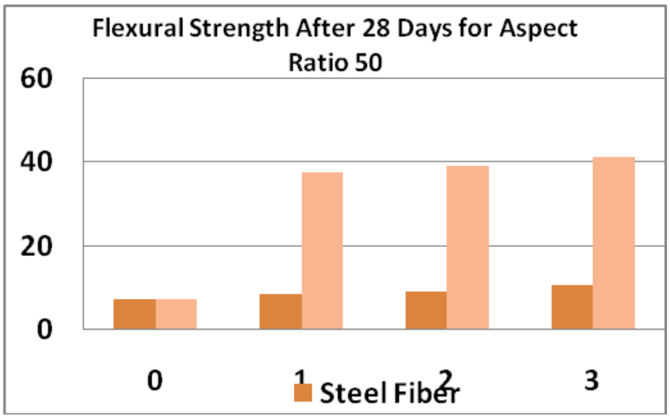

Figure 3: Flexural strength after 28 days for aspect ratio 50

Figure 3 is showing a big change in flexural strength in polypropylene fibers with respect to steel fibers. At 1% mixing of fibers, strength of steel fiber concrete was 15% whereas strength of polypropylene fibers was 80%. In case of 2% mixing of fibers, 21% gained for steel fibers, and 81% gained for polypropylene fibers. Similarly for 3% addition of fibers, steel fiber strength increased 32% whereas 83% strength increased for polypropylene fibers with respect to conventional concrete.

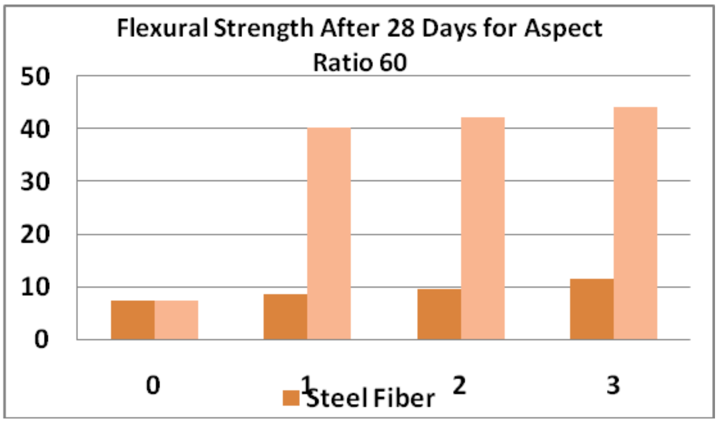

Figure 4: Flexural strength after 28 days for aspect ratio 60

From figure 4, the obtained results are very clear that after 3% addition of polypropylene fibers, the increased strength is 83.5% with respect to nominal concrete. Gained strength between 2% to 3% in polypropylene fibers is 4% whereas for steel fibers these changes are 16% for same. A comparison of steel and polypropylene fibers at 1% is 78.5%, at 2% is 77% and at 3% is 73%. The graphical presentation and analysis shows that a small change in strength is totally depend on percentages of fibers.

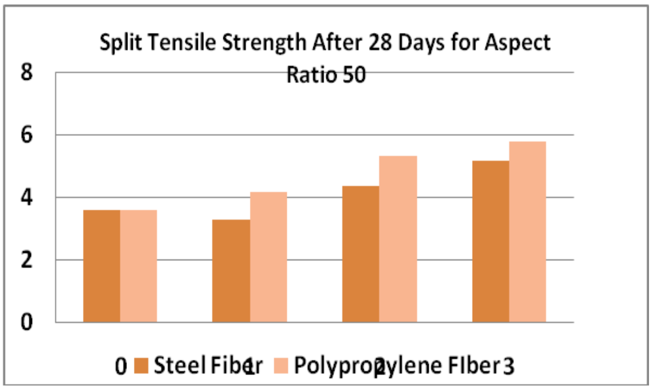

Figure 5: Split Tensile strength after 28 days for aspect ratio 50

Figure 5 is telling the strength of steel fibers at 1% with conventional concrete i.e. fiber free is decreased with 9% whereas for polypropylene fibers, strength increased with 14%. Split tensile strength comparison between 1% and 2% of steel fibers is showing 25% change whereas in polypropylene fibers 21%.

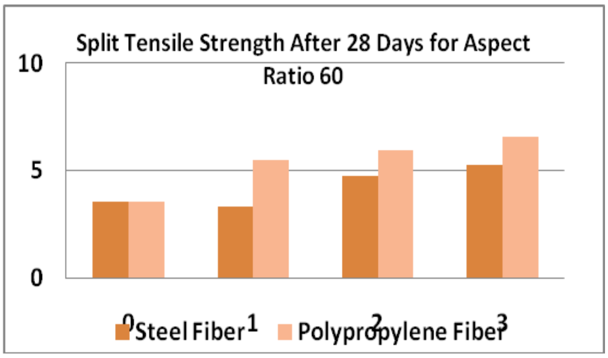

Figure 6: Split Tensile strength after 28 days for aspect ratio 60

Figure 6 is a comparison between split tensile strengths of steel and polypropylene fibers. At 1% of steel fiber addition, 6% strength decreased whereas at 2% addition of same, strength increased 25% with respect to conventional concrete. In polypropylene fiber mixing with conventional concrete, strength increased at 1% is 35% and at 2% is 40%. At 3% for both, polypropylene fibers are showing 13% more capable to check the strength as compared to steel.

5. CONCLUSIONS

In this present study with the stipulated time and laboratory set up afford has been taken to enlighten the use of so called fiber reinforced concrete in accordance to their proficiency. It was concluded that:

- With the use of super-plasticizer, it is possible to get a mix with low water to cement ratio to get the desired strength.
- In case of Ordinary Portland Cement with the use of steel fiber, the 28 days compressive strength at 3% fiber content the result obtained is maximum.
- When polypropylene fiber mixed with nominal concrete, it shows compressive strength is less than steel i.e. 11%.
- After mixing of fibers (i.e. steel & polypropylene) with by 1%,2% and 3%, the compressive strengths increases gradually. Which means slightly changes comes by increasing the percentage fibers for both aspect ratios.
- As shown in graphs for aspect ratios i.e. 50 and 60, compressive strength changes maximum limit in aspect ratio 60. This shows if the length of fibers is more, then compressive strengths will be more.
- When there is no mixing of fibers, no changes will come in any strength.
- Maximum flexural strength is coming in polypropylene, it means for casting of beams is helpful by using the polypropylene fibers.
- The orientations of fibers also giving a good result for polypropylene fibers. Because as compared to steel, it is more flexible and able to resist the uniformly distributed loads.
- The flexural strength for aspect ratio 60 and polypropylene fibers is showing a long gap between steel and polypropylene fibers.
- If we compare the split tensile strength, for the aspect ratio 50, it is 10% variation between steel and polypropylene. Whereas for aspect ratio 50, it is approximately 20% variation in same.
- Polypropylene fibers will be more effective in tensile zone because they have property of plasticity.

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