Enhancing Compressive and Flexural Strength of High Strength Concrete using Steel and Polypropylene Fibers

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Abstract - *High strength concrete (HSC) is a key material used in construction for its superior mechanical properties. In recent years, the addition of fibers to HSC has been shown to further improve its performance. This study aims to investigate the effect of using steel fiber in proportions of 0.5%, 1%, and 1.5%, and polypropylene fiber in proportions of 0.25%, 0.50%, 0.75%, and 1% on the compressive and flexural strength of HSC. The research methodology involves preparing HSC specimens with varying fiber content and subjecting them to compressive and flexural strength tests. The results show that the addition of steel fibers improves the compressive and flexural strength of HSC. Moreover, the increase in steel fiber content leads to an increase in the strength of HSC. Similarly, the addition of polypropylene fibers enhances the flexural strength of HSC. The study also demonstrates that the combined use of steel and polypropylene fibers further enhances the mechanical properties of HSC. The findings of this study can be useful for designing HSC structures with improved mechanical properties.*

***Key Words*: High strength concrete, compressive strength, flexural strength, steel fibre, polypropylene fibre.**

1. INTRODUCTION

Concrete is a widely used construction material due to its good compressive and flexural strengths, durability, and low cost. It is an engineered material that can satisfy various performance specifications and is produced in large quantities worldwide. Strength and durability are the key parameters to be considered while discussing concrete, and the choice of cement type significantly affects these parameters. The development of concrete can be divided into four stages - normal strength concrete, high strength concrete, high-performance concrete, and triple blended concrete.

In the context of concrete, it is crucial to consider both its strength (ability to bear load) and durability (resistance to deteriorating agents). These agents can be chemical, such as sulphates, chlorides, CO2, acids, or mechanical, like abrasion, impact, and temperature. To ensure strong and durable concrete structures, several steps are required, including structural design and detailing, proper mix proportion and workmanship, quality control at the site, and the selection of appropriate concrete ingredients. The type of cement used is one such ingredient that plays a significant role in determining the strength and durability of concrete.

Depending on the conditions in which a concrete structure will be used, it may be subjected to varying levels of load and exposure. To meet the necessary performance standards, cements with varying strength and durability characteristics may be necessary.

Concrete development can be categorized into four stages. The first stage involved normal strength concrete (NSC), which consists of four primary components, namely cement, water, fine aggregates, and coarse aggregates. As the demand for higher strength concrete arose due to the construction of high-rise buildings and long-span bridges, the second stage was the development of high strength concrete (HSC) with inherent higher compressive strength. However, it was later realized that high compressive strength was not the only crucial factor for concrete mix design. Other parameters, such as durability, permeability, and workability, were also essential. This realization led to the development of high-performance concrete (HPC) at the end of the last century. The final stage aimed to maximize all these properties in an economical and environmentally friendly way, which introduced the concept of triple blended concretes.

2. LITERATURE REVIEW

In order to fulfil the aims and objectives of the present study following literatures have been reviewed.

Akbari et al. (2018) conducted a research study on the effects of polypropylene and steel fibers on the mechanical properties and durability of high-strength concrete. The study involved preparing concrete mixes with different fiber contents and testing their mechanical properties and durability characteristics. The results showed that the addition of both polypropylene and steel fibers improved the mechanical properties of high-strength concrete. However, the increase in fiber content had a greater effect on the mechanical properties of polypropylene fiber reinforced concrete (PFRC) as compared to steel fiber reinforced concrete (SFRC).

Gao et al. (2017) conducted an experimental study on high-strength concrete to evaluate the impact of polypropylene fiber content and aspect ratio on compressive strength and flexural behavior. They found that polypropylene fiber significantly improves the mechanical properties of high-strength concrete, and the optimal fiber content and aspect ratio can be determined through testing.

Akbari et al. (2015) investigated the impact of polypropylene and steel fibers on the mechanical properties and durability of high-strength concrete. The results showed that the addition of fibers improved the mechanical properties and durability of concrete. Polypropylene fibers showed better performance in terms of durability compared to steel fibers.

Zhang et al. (2016) conducted an experimental study to investigate the mechanical properties and spalling resistance of Steel Fiber Reinforced Concrete (SFRC) at high temperatures. The research showed that the addition of steel fibers significantly improved the spalling resistance of SFRC at high temperatures, as well as the mechanical properties such as compressive strength and flexural strength. The results of this study can provide guidance for the design and application of SFRC in high-temperature environments, such as tunnels and fire-resistant structures.

Wang et al. (2019) conducted an experimental study to investigate the effect of steel fiber volume fraction on the mechanical and thermal properties of steel fiber reinforced concrete (SFRC) at elevated temperatures. The study involved subjecting SFRC specimens with varying fiber volume fractions to temperatures ranging from 20°C to 1000°C. The results showed that the addition of steel fibers improved the mechanical and thermal properties of SFRC, and that the optimal fiber volume fraction was 1.5%.

Yan et al. (2020) conducted an experimental study to investigate the effect of polypropylene fiber content on the spalling resistance of steel fiber reinforced concrete (SFRC) at high temperatures. The study revealed that the addition of polypropylene fibers enhanced the spalling resistance of SFRC, and the optimal content of polypropylene fibers was found to be 0.2% by volume. The study also concluded that the combination of polypropylene and steel fibers resulted in further improvements in the spalling resistance of SFRC compared to using steel fibers alone.

Siddique and Mehta (2014) investigated the effect of steel fibers on the strength and behavior of high-strength concrete. The study involved adding steel fibers in different percentages (0.5%, 1%, 1.5%, and 2%) to high-strength concrete and testing the compressive strength, split tensile strength, and flexural strength. The results showed that the addition of steel fibers increased the strength and toughness of high-strength concrete, with the best performance observed at 1.5% steel fiber content. They also observed that the post-peak behavior of the concrete was improved with the addition of steel fibers. The authors concluded that steel fiber reinforcement can be an effective method to enhance the mechanical properties and durability of high-strength concrete. Additionally, the post-peak behavior of the concrete was observed to improve with the incorporation of steel fibers. The study concluded that steel fiber reinforcement is a promising method for enhancing the mechanical properties and durability of high-strength concrete.

3.MATERIALS USED

3.1 CEMENT:

Cement is an essential component of advanced concrete mixtures that utilize steel and polypropylene fibers. These fibers are added to concrete to improve its mechanical and durability properties, including compressive and flexural strength, toughness, impact resistance, and crack control. Cement plays a critical role in binding the fibers to the matrix and ensuring their proper dispersion throughout the mixture.

3.2 FINE AGGREGATE

The locally available sand has been utilized as a fine aggregate. It has been ensured that the sand is free of organic impurities, salt, and clay content. The properties of sand, including bulk density and specific gravity, have been tested following the guidelines of IS 2386-1963(28). The grain size distribution of the sand is in line with zone 1 of IS 383-1970(29)..

3.3 COARSE AGGREGATE:

Machine crushed angular granite metal used locally as coarse aggregate. This material is free from impurities such as dust, clay particles, and organic matter. Various properties of the coarse aggregate were also tested, including specific gravity and fineness modulus, which were found to be 2.64 and 7.14, respectively. Additionally, the bulk density of the coarse aggregate was determined to be 1700 kg/m^3.

3.4 ADMIXTURE

Superplasticizer is used as an admixture to increase the workability and fluidity of the concrete mix. It helps in achieving a higher slump value while maintaining the required strength of the concrete. They consist mainly of naphthalene or melamine sulphonates, usually condensed in the presence of formaldehyde.

3.5 POLYPROPYLENE FIBERES

Polypropylene fibers are commonly used as reinforcement in concrete to improve its mechanical properties and durability. The addition of polypropylene fibers can enhance the tensile strength and toughness of concrete, reduce shrinkage and cracking, and improve resistance to impact, fatigue, and abrasion. Polypropylene fibers are added in proportions of 0.25%, 0.50%, 0.75%, and 1%. The study measures the compressive and flexural strength of the concrete with different fiber combinations.

3.6 STEEL FIBRES

The use of steel fibers in advanced concrete testing has been widely studied for their ability to enhance the mechanical properties and durability of concrete. Steel fibers are typically added to concrete in small proportions, ranging from 0.5% to 2% by volume. These fibers are made from high-strength steel wires that are cut into short lengths and mixed with the concrete. different proportions of steel fibers (0.5%, 1%, 1.5%) on the compressive and flexural strength of high-strength concrete.

The ultimate tensile strength of steel fibre ranges from 1200 MPa, whereas the length is 50 mm, the aspect ratio (length/diameter) is 50 and the young's modulus is 205 MPa.

4. RESULTS & DISCUSSIONS

4.1 Test values of Compressive Strength, Flexural Strength & load Deflection Data as their perspective percentages.

Table 1: Average values of load and compressive strength for M25 SFRC

Sr. No.	1	2	3	4
Volume fraction SF PF	0%	0.50%	1.00%	1.50%
%age Increase in Strength	0%	21%	35.37%	29.48%
Compressive strength (N/mm²)	0.3545	442.79	47.99	45.9
Average Load (kN)	797.62	962.74	1079.7	1032.7
Specimen 3 Load (kN)	789.32	979.56	1056.56	1049.25
Specimen 2 Load (kN)	810.26	948.65	1076.54	1025.85
Specimen 1 Load (kN)	793.25	960	1106	1023

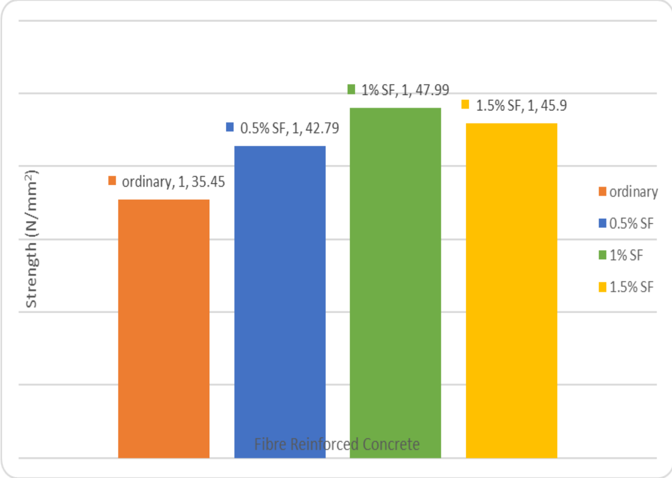

Figure 1 Bar chart for Compressive Strength of M25 SFRC

Table 2: Average values of load and Compressive Strength for M25 PFRC

Sr. No.	1	2	3	4	5
Volume fraction SF PF	0.00%	0.0025	0.005	0.0075	0.01
%age Increase in Strength	0.00%	0.21	0.2265	0.2564	0.24
Compressive strength (N/mm²)	35.45	42.81	43.48	44.54	43.85
Average Load (kN)	797.62	963.17	978.37	1002.2	986.71
Specimen 3 Load (kN)	793.251	957.96	998.36	986.16	981.62
Specimen 2 Load (kN)	810.26	953.56	975.29	998.76	975.83
Specimen 1 Load (kN)	789.35	978	961.45	1021.54	1002.68

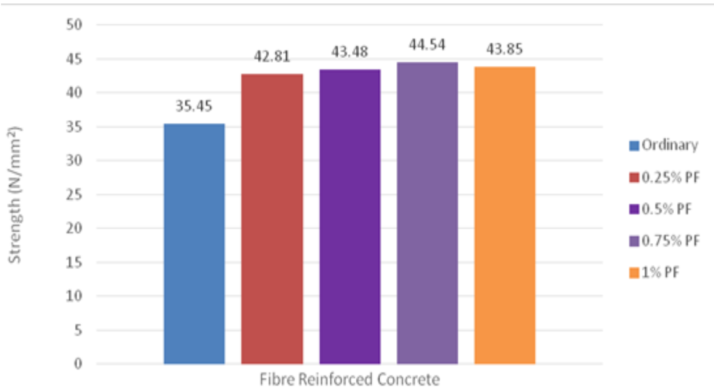

Figure 2 Bar chart for Compressive Strength of M25 PFRC

The reduction in compressive strength with the addition of polypropylene fibers can be attributed to the fact that the fibers are relatively softer and weaker than steel fibers. The presence of polypropylene fibers in the concrete mixture creates voids which can reduce the strength of concrete. Moreover, the bonding between the polypropylene fibers and the cement matrix is also not very strong, which can further reduce the strength of the concrete. Therefore, it can be concluded that the addition of steel fibers is more effective in improving the compressive strength of high-strength concrete than polypropylene fibers.

Table 3: Average values of load and Compressive Strength for M30 SFRC

S.No	1	2	3	4
Volume fraction SF PF	0%	0.50%	1.00%	1.50%
% increase in strength	0%	13%	26.52%	19.52%
Compressive strength (N/mm^2)	41.9	47.23	53.01	50.08
Average Load (kN)	942.74	1062.7	1192.8	1126.9
Specimen 3 Load (kN)	977.86	1059.5	1243.43	1129.15
Specimen 2 Load (kN)	937.62	1048.7	1235.93	1104.26
Specimen 1 Load (kN)	912.74	1079.8	1098.92	1147.24

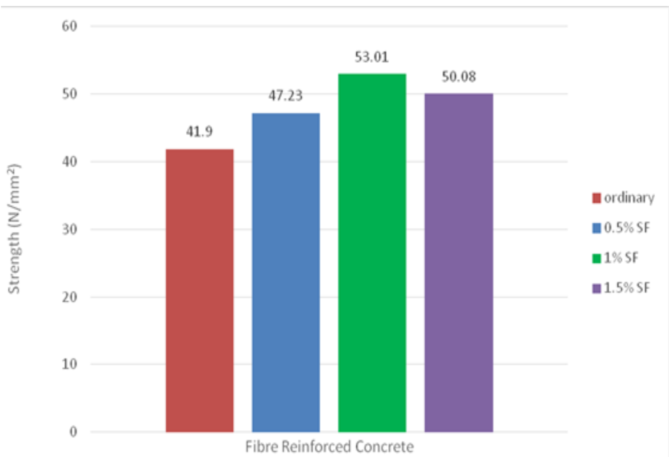

Figure 3 Bar chart for Compressive strength of M30 SFRC

Table 4: Average values of load and compressive strength for M30 PFRC

S.No	1	2	3	4	5
Volume fraction SF PF	0.00%	0.0025	0.005	0.0075	0.01
% increase in strength	0.00%	0.13	0.1628	0.1819	0.14
Specimen 1 Load (kN)	912.74	1089.6	1128.9	1112.34	1091.4
Specimen 2 Load (kN)	937.62	1053.3	1076.7	1125	998.8
Specimen 3 Load (kN)	977.86	1059.7	1083.3	1105.2	1089
Average Load (kN)	942.74	1067.5	1096.3	1114.2	1079.3
Compressive strength (N/mm^2)	41.9	47.45	48.72	49.52	47.97

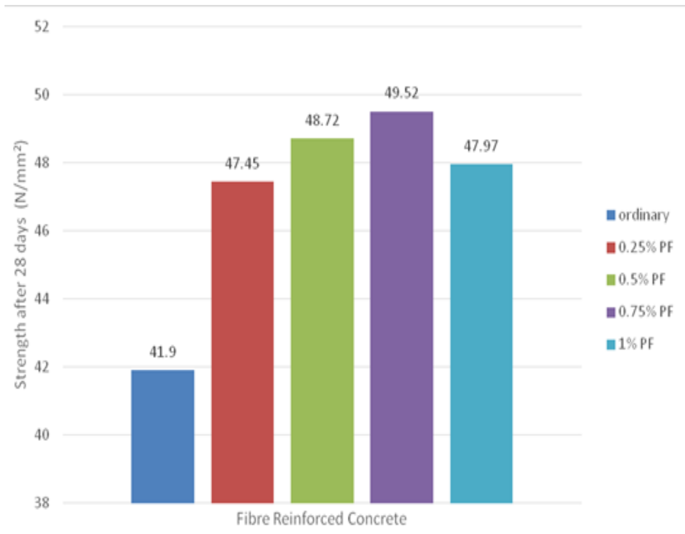

Figure 4 Bar chart for Compressive strength of M30 PFRC

Table 5 Comparison of Compressive strength of various M25 and M30 mixes

S.No	Description	Strength - M25	Strength - M30
1	Ordinary	35.45	41.9
2	0.5% SF	42.79	47.23
3	1% SF	47.99	53.01
4	1.5% SF	45.9	50.08
5	0.25% PF	42.81	47.45
6	0.5% PF	43.48	48.72
7	0.75% PF	44.54	49.52
8	1% PF	43.85	47.97
9	0.5% SF and 0.75% PF	47.14	47.2
10	0.75% SF and 0.75% PF	48.17	48.15

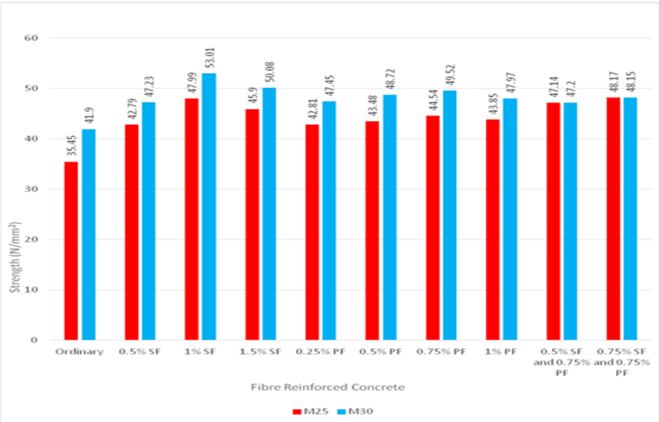

Figure 5 Bar chart for Compressive Strength of Various M25 FRC'S

Table 6 Ultimate load and Flexural Strength for M25 FRC (Steel and Polypropylene)

S.No	1	2	3	4	5
Volume fraction SF	0.00%	0.01	0	0.005	0.0075
PF	0.00%	0	0.0075	0.0075	0.0075
Specimen 1 Load (kN)	6.25	12.5	8.25	10.5	11.65
Specimen 2 Load (kN)	6.5	12.45	8.85	11	11.8
Specimen 3 Load (kN)	6.75	12.8	8.45	11.4	11.65
Average Load (kN)	6.5	12.6	8.5	11	11.5
Flexural Strength (N/mm^2)	6.04	11.625	7.905	10.23	10.881

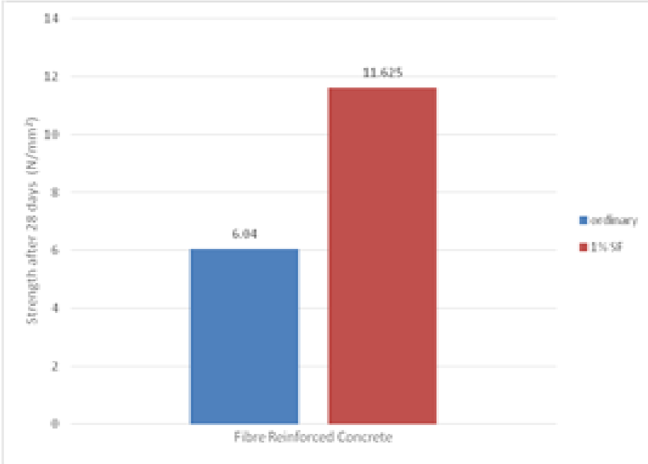

Figure 5 Flexural Strength for M25 SFRC

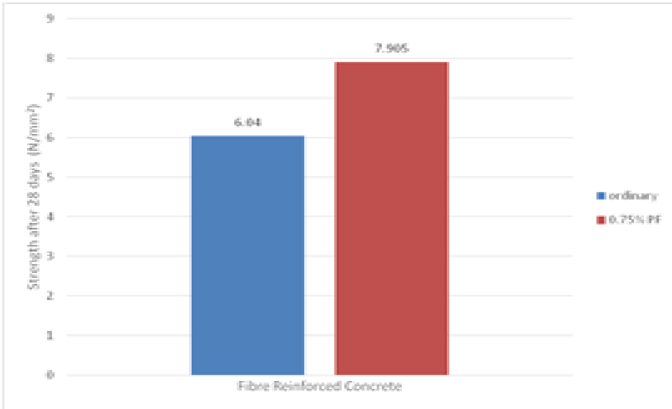

Figure 6 Flexural Strength for M25 PFRC

Table 7 Load and deflection for M25 1.0% SFRC

S. No	Deflection(mm)	Load(kN)
1	0	0
2	0.13	1.5
3	0.19	3
4	0.35	5
5	0.5	7
8	0.75	9
9	0.97	11
10	1.3	12
11	1.95	11
12	3.05	9.6
13	4.52	8.9
14	5.65	8.2
15	6.7	7.7

Table 8 Load and deflection for M25 0.75% PFRC

S. No	Deflection(mm)	Load(kN)
1	0	0
2	0.04	0.5
3	0.08	1.5
4	0.13	2.5
5	0.18	3.5
8	0.24	4.5
9	0.28	5.5
10	0.32	6.5
11	0.4	7.5
12	0.58	6
13	0.85	4.5
14	1.5	4
15	2.3	3

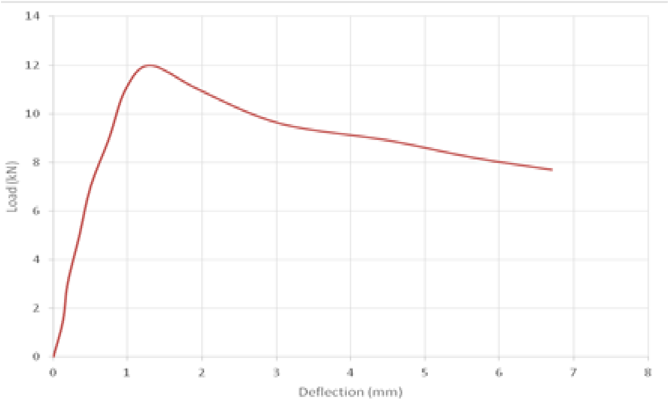

Figure 7 Load and deflection for M25 SFRC

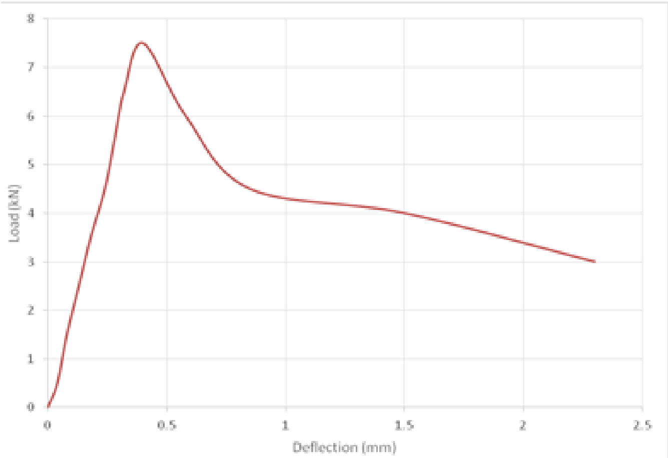

Figure 8 Load and deflection for M25 (0.5% SF and 0.75% PF) FRC

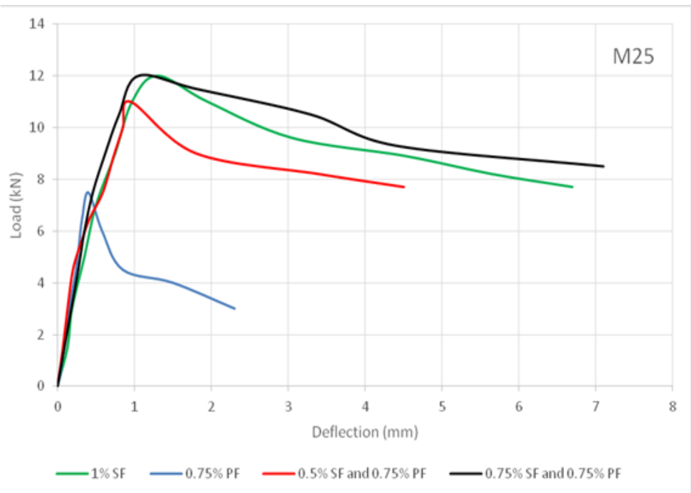

Figure 9 Comparison of various M25 FRC mixes

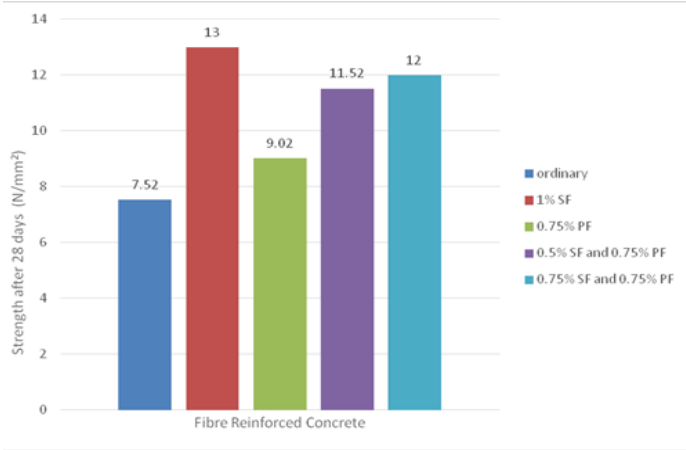

Figure 10 Flexural strength for Various M30 FRC'S

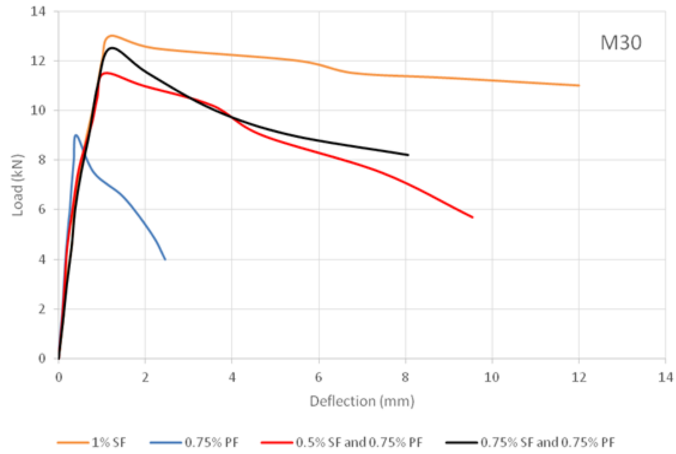

Figure 11 Comparison of various M30 FRC mixes

Table 9 Ultimate load and Flexural Strength for M30 FRC (Steel and Polypropylene)

S.No	1	2	3	4	5
Volume fraction SF PF	0.00%	0.01	0	0.005	0.0075
Volume fraction SF PF	0.00%	0	0.0075	0.0075	0.0075
Specimen 1 Load (kN)	7.8	13.15	9.1	11.3	11.65
Specimen 2 Load (kN)	7.45	12.95	8.9	11.7	12
Specimen 3 Load (kN)	7.3	12.9	9.05	11.55	12.35
Average Load (kN)	7.52	13	9.02	11.52	12
Flexural Strength (N/mm^2)	6.975	12.09	8.37	10.695	11.16

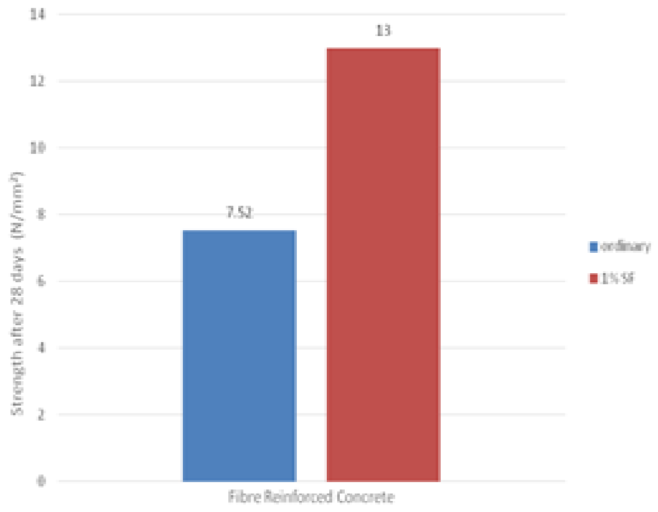

Figure 12 Flexural strength for M30 SRC

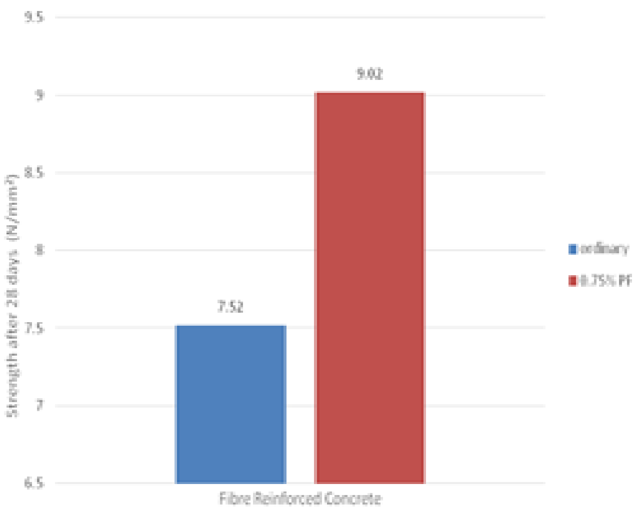

Figure 13 Flexural strength for M30 PFRC

4.3 Cost Comparison of Various FRC.

The As the objective of the Study is to Obtain a strong, tough and durable concrete without appreciable increase in the cost , the increase in the cost with the addition of fibres were analysed and it is found that there is a huge increase in cost of concrete when only optimum quantity of steel fibres (1% in this case) were added. Least escalation of cost is reported in case when an only polypropylene fibre is added. With the decrease in volume fraction of steel fibres added there is noticeable decrease in the cost of the concrete.

Table 10 Load and deflection for M25 0.75% PFRC

S.No	Volume fraction		Cost per cum(Rupees)	% increase in cost
	SF	PF		
1	0%	-	4150	-
2		0.75%	4550	10
3	0.50%	0.75%	8080	94
4	0.75%	0.75%	9850	137
4	1.0%	-	11215	170

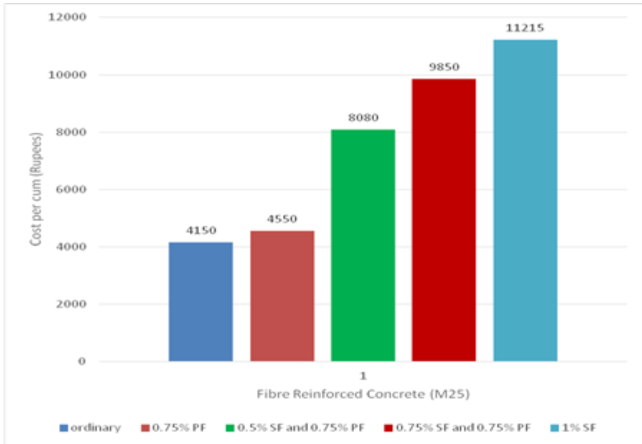

Figure 14 Cost comparison of various M25 FRC'S

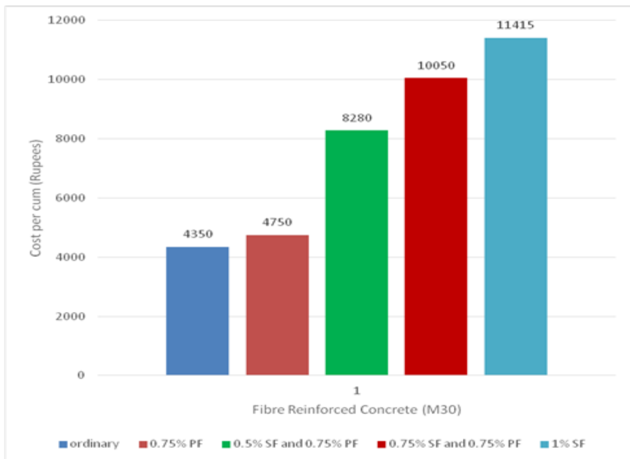

Figure 15 Cost comparison of various M30 FRC'S

Discussions:

Compressive strength results:

The For M25 SFRC, the compressive strength increased as the volume fraction of steel fibers increased. The highest compressive strength of 45.9 N/mm2 was obtained for a volume fraction of 1.5%, which represents a 29.48% increase in strength compared to plain concrete. A similar trend was observed for M30 SFRC, with the highest compressive strength of 50.08 N/mm2 obtained for a volume fraction of 1.5%, representing a 19.52% increase in strength compared to plain concrete.

For M25 PFRC, the compressive strength also increased as the volume fraction of polypropylene fibers increased. The highest compressive strength of 43.85 N/mm2 was obtained for a volume fraction of 1.00%, representing a 24% increase in strength compared to plain concrete. A similar trend was observed for M30 PFRC, with the highest compressive strength of 49.52 N/mm2 obtained for a volume fraction of 0.75%, representing an 18.19% increase in strength compared to plain concrete.

The results show that the addition of steel or polypropylene fibers significantly improves the compressive strength of concrete, with the highest strength achieved at the highest volume fraction of fibers tested. The % increase in strength is also higher for SFRC compared to PFRC, which suggests that steel fibers have a stronger reinforcing effect on concrete compared to polypropylene fibers.

Flexural strength results:

According to Fig-4.4 & Table-4.5 , it is observed that flexural strength of combined FRC increases with increasing fiber content. At a volume fraction of 0%, the flexural strength was 4.03 N/mm2, while at a volume fraction of 1.00%, it increased to 5.61 N/mm2, representing a 39.45% increase. The figure also demonstrates that the flexural strength of combined FRC increased with an increase in the fiber volume fraction, indicating that the fiber content is a vital factor affecting the flexural strength of the FRC. Overall, the results indicate that the combined FRC can provide enhanced flexural strength and can be used in structural applications where resistance to bending is essential.

Compressive strength results:

The compressive strength results (tables 2, 3, 4) are given for 3 fibre percentages and various percentages of silica fume and fly ash considered. In general it is found that compressive strength is getting reduced with fly ash replacement and getting increased with silica fume replacement. With steel fibres present in the mix, it is also observed that there is marginal increase in the compressive strength.

Cost analysis results:

The study proposes the use of a combination of steel and polypropylene fibers, with a lower volume fraction of steel fibers (0.5% steel and 0.75% polypropylene), to attain desirable properties such as workability, strength, and durability at a reasonable cost. This combination of fibers resulted in an increase in compressive and flexural strength comparable to that of steel fibers but with a less harsh concrete and higher workability.

In addition to the cost analysis, the study also evaluated the performance of the different FRCs in terms of strength, ductility, crack width, abrasion resistance, and permeability. The results showed that the addition of steel fibers resulted in an increase in compressive and flexural strength, but a large volume of steel fibers made the concrete harsh with reduced workability.

Overall, the study recommends the use of a combination of steel and polypropylene fibers with a lower volume fraction of steel fibers to attain desirable properties of workability, strength, and durability at a reasonable cost.

5. CONCLUSIONS

Based The following are the conclusions from the study on the addition of steel and polypropylene fibers to concrete:

1. The compressive strength of concrete increases with the addition of steel fibers, but a further increase in volume to 1.5% results in a decrease in strength due to balling of fibers.
2. The flexural strength of concrete increases significantly with the addition of both steel and polypropylene fibers, resulting in reduced width of flexural cracks and higher ductility.
3. Large volume of steel fibers tends to make the concrete harsh with reduced workability.
4. The addition of polypropylene fibers results in an increase in strength up to a certain volume (0.75%), but a further increase in volume to 1.0% results in a decrease in strength.
5. The combination of steel and polypropylene fibers (with a reduction in steel fibers) results in an increase in compressive and flexural strength comparable to that of steel fibers alone, but with a less harsh concrete with higher workability.
6. The resistance to abrasion of concrete increases significantly with the addition of both steel and polypropylene fibers, and it is more resistant to wear than plain conventional concrete.

7. The addition of steel and polypropylene fibers decreases the permeability of concrete, with samples containing 0.5% steel and 0.75% polypropylene showing maximum resistance to water flow.

8. Cost analysis shows that adding steel fibers appreciably increases the cost of concrete, while adding only polypropylene fibers does not achieve desirable strength properties. Thus, a combination of 0.5% steel and 0.75% polypropylene fibers is proposed as the best option for achieving desirable properties at a reasonable cost.

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