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Influence of Fibres on Concrete

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Abstract: Concrete is the most widely used construction material, but its compressive strength can be limited by its brittle nature and susceptibility to cracking. This study investigates the effects of hybrid fiber reinforcement on the compressive strength of concrete by incorporating different types of fibers, such as steel, polypropylene, and glass, in varying proportions. A comparative analysis was conducted to assess the influence of hybrid fibers on strength development over time. Experimental results indicate that hybrid fiber-reinforced concrete (HFRC) exhibits significantly higher compressive strength compared to conventional concrete. The synergistic effect of multiple fiber types enhances load distribution and resistance to failure under cmpressive loads. This research highlights the potential of HFRC for high-performance structural applications, recommending further studies on optimizing fiber proportions for maximum compressive strength.
Keywords: Concrete, Hybrid Fiber, Compressive Strength, Steel Fiber, Polypropylene Fiber, Glass Fiber.

I. INTRODUCTION

Concrete is pivotal to modern infrastructure, owing to its excellent compressive strength, durability, and economic feasibility. It is extensively employed in bridges, tall structures, pavements, and other load-intensive applications. Nonetheless, traditional concrete suffers from brittleness and crack susceptibility, especially under high loads, leading to reduced durability and potential structural failures over time.

To overcome these limitations, fiber reinforcement has emerged as a prominent solution. Fibers act to bridge cracks, redistribute stress, and enhance the overall structural integrity of concrete. Particularly, Hybrid Fiber-Reinforced Concrete (HFRC)—which integrates multiple fiber types such as steel, polypropylene, and glass—has shown superior performance compared to single-fiber reinforcement. Each fiber type offers distinct advantages: steel fibers improve strength and toughness, while synthetic fibers like polypropylene control shrinkage cracking and enhance ductility.

Past research has consistently demonstrated that hybrid reinforcement strategies can notably augment compressive strength and durability. However, the effectiveness of HFRC largely depends on fiber selection, proportioning, and distribution. This study focuses on analyzing the influence of hybrid fiber combinations on compressive strength, aiming to develop an optimized fiber-reinforced concrete for sustainable and resilient construction.

II. METHODOLOGY

Concrete mixes were designed for M25 and M30 grades. The quantities for M25 and M30 are shown in table below. Standard procedures were followed, where cement (OPC), fine aggregates, coarse aggregates, and potable water were used. Concrete cubes of dimensions 150 mm × 150 mm × 150 mm were cast.

Table A.1 Material Quantity for M25 and M30

Materials	Quantity(M25)	Cost Rs/(1m^3) (M25)	Quantity (M30)	Cost Rs/(1m^3) (M30)
Cement	350.38kg	2452.45/-	366.35kg	2564.45/-
Water	164.68kg	0	164.86kg	0
Coarse Aggregate	986.26kg	1007.95/-	989.22kg	1010.98/-
Fine Aggregate	716.50kg	1528.29/-	697.88kg	1488.51/-
Plasticizer	0.70kg	70/-	1.097kg	109.7/-
Total	5173.64/-		5058.69/-	

Cube moulds were cleaned, oiled, and assembled prior to casting. Mixing was performed mechanically for at least 3 minutes, followed by placing the mix in moulds in three layers with each layer compacted by tamping 25 times.

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Post 24-hour casting, specimens were demoulded, labeled, and cured in water tanks for periods of 3, 7, and 28 days.

Fiber Types and Dosages

Concrete was reinforced with different fibers:

a. Glass fibers at 0.33%, 0.67%, and 1% by volume
b. Steel hooked fibers at 0.2%, 0.4%, and 0.7% by volume
c. Steel plain fibers at 0.2%, 0.4%, and 0.7% by volume
d. Polypropylene Macro fibre at 0.2%, 0.4%, and 0.6% by volume
e. Polypropylene Micro fibre at 0.2%, 0.4%, and 0.6% by volume

Hybrid fiber combinations were also cast:

a. Steel plain (0.25%) + Steel hooked (0.25%) + Glass fiber (0.5%)
b. Polypropylene macro (0.25%) + Polypropylene micro (0.25%) + Glass fiber (0.5%)
c. Steel plain (0.25%) + Steel hooked (0.25%) + Polypropylene macro (0.25%) + Polypropylene micro (0.25%)
d. Steel hooked (0.5%) + Glass fiber (0.5%)
e. Polypropylene macro (0.5%) + Steel hooked (0.5%)
f. Steel plain (0.5%) + Glass fiber (0.5%)

Testing Procedures

At the end of the curing periods, compressive strength tests were conducted on a Compression Testing Machine (CTM). The average compressive strength was calculated for each set of three cubes.

III. RESULTS AND DISCUSSIONS

The test results from compression test for control cube, single fibre specimen and hybrid fibres are given in table 4.1, table 4.2 and table 4.3 and results are discussed below.

Table A.2 Results of Control Specimens

Grade of concrete mix	Days	Cube 1 (Mpa)	Cube 2 (Mpa)	Cube 3 (Mpa)	Average Compressive Strength (MPa)
M25	3	14.40	14.38	14.36	14.38
M25	7	21.56	23.42	21.86	22.28
M25	28	32.22	31.32	32.04	31.86
M30	3	18.21	17.07	16.38	17.22
M30	7	25.97	27.24	27.12	26.77
M30	28	38.72	38.46	37.64	38.27

Table A.3 Results of Individual Fibres Specimen

Fibre and their percent	Days	Cube 1 (Mpa)	Cube 2 (Mpa)	Cube 3 (Mpa)	Average Compressive Strength (MPa)	Percent increase in compressive strength (%)
Glass fibre (0.33%)	3	16.42	17.46	18.42	17.43	21.02
Glass fibre (0.33%)	7	26.66	27.46	26.62	26.91	20.78
Glass fibre (0.33%)	28	37.33	42.40	37.91	38.21	19.93
Glass fibre (0.67%)	3	17.36	18.06	18.12	17.84	24.06

Glass fibre (0.67%)	7	25.15	25.86	26.75	25.92	16.33
Glass fibre (0.67%)	28	39.33	38.22	38.46	38.67	21.37
Glass fibre (1%)	3	18.44	18.16	19.64	18.90	31.43
Glass fibre (1%)	7	27.25	27.55	27.73	27.50	23.42
Glass fibre (1%)	28	38.00	39.68	39.70	38.97	22.31
Steel hooked fibre (0.2%)	3	17.42	17.89	18.13	17.81	23.85
Steel hooked fibre (0.2%)	7	26.84	29.15	25.68	27.22	22.17
Steel hooked fibre (0.2%)	28	38.36	38.56	38.41	38.44	20.65
Steel hooked fibre (0.4%)	3	19.02	17.87	18.41	18.43	28.16
Steel hooked fibre (0.4%)	7	27.11	27.33	28.08	27.50	23.42
Steel hooked fibre (0.4%)	28	39.01	38.56	38.78	38.78	21.72
Steel hooked fibre (0.7%)	3	19.12	18.48	20.22	19.27	34.00
Steel hooked fibre (0.7%)	7	27.53	27.94	27.45	27.64	24.05
Steel hooked fibre (0.7%)	28	39.33	38.48	39.22	39.003	22.41
Steel plain fibre (0.2%)	3	18.12	17.56	17.47	17.71	23.15
Steel plain fibre (0.2%)	7	27.42	26.31	27.12	26.95	20.96
Steel plain fibre (0.2%)	28	37.87	38.94	38.12	38.31	20.24
Steel plain fibre (0.4%)	3	17.92	18.48	18.77	18.39	27.88
Steel plain fibre (0.4%)	7	28.04	26.72	27.36	27.37	22.84
Steel plain fibre (0.4%)	28	38.19	39.56	37.97	38.57	21.06
Steel plain fibre (0.7%)	3	18.48	19.12	20.11	19.23	33.72
Steel plain fibre (0.7%)	7	26.92	27.39	28.66	27.65	24.10
Steel plain fibre (0.7%)	28	38.77	39.04	39.87	39.22	23.10
Macro Polypropylene Fibres (0.2%)	3	15.23	16.59	17.24	16.3	13.35
Macro Polypropylene Fibres (0.2%)	7	26.68	26.17	24.86	25.90	16.24

Macro Polypropylene Fibres (0.2%)	28	38.07	37.23	37.12	37.47	17.60
Macro Polypropylene Fibres (0.4%)	3	16.43	15.98	16.98	16.46	14.46
Macro Polypropylene Fibres (0.4%)	7	25.91	26.54	26.98	26.47	18.80
Macro Polypropylene Fibres (0.4%)	28	38.74	37.25	37.64	37.87	18.86
Macro Polypropylene Fibres (0.6%)	3	18.04	18.12	17.45	17.87	24.26
Macro Polypropylene Fibres (0.6%)	7	24.69	25.23	24.78	24.09	8.12
Macro Polypropylene Fibres (0.6%)	28	37.98	38.23	37.54	37.91	18.98
Micro Polypropylene Fibres (0.2%)	3	15.82	17.33	16.49	16.54	15.02
Micro Polypropylene Fibres (0.2%)	7	26.02	26.33	25.42	25.92	16.33
Micro Polypropylene Fibres (0.2%)	28	37.34	38.13	37.45	37.64	18.14
Micro Polypropylene Fibres (0.4%)	3	17.79	15.75	16.55	16.69	16.06
Micro Polypropylene Fibres (0.4%)	7	26.45	26.87	26.79	26.70	19.83
Micro Polypropylene Fibres (0.4%)	28	37.64	38.36	37.64	37.88	18.89
Micro Polypropylene Fibres (0.6%)	3	18.28	17.47	17.25	17.66	22.80
Micro Polypropylene Fibres (0.6%)	7	25.09	24.98	24.91	24.99	12.16
Micro Polypropylene Fibres (0.6%)	28	37.56	37.98	38.23	37.92	19.09

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Table A.4 Results of Hybrid Fibres Specimen

Hybrid fibre (1 % by vol in whole)	Days	Cube 1 (Mpa)	Cube 2 (Mpa)	Cube 3 (Mpa)	Average Compressive Strength (MPa)	Percent increase in compressive strength (%)
Steel plain (0.25%) + steel hooked (0.25%) + glass fibre (0.5%)	3	18.98	19.58	19.67	19.41	34.97
Steel plain (0.25%) + steel hooked (0.25%) + glass fibre (0.5%)	7	29.03	28.42	28.12	28.52	28
Steel plain (0.25%) + steel hooked (0.25%) + glass fibre (0.5%)	28	39.35	38.95	38.61	38.97	22.31
Polypropylene macro (0.25 %) + Polypropylene micro (0.25 %) + glass fibre (0.5%)	3	18.42	19.67	19.13	19.07	32.61
Polypropylene macro (0.25 %) + Polypropylene micro (0.25 %) + glass fibre (0.5%)	7	28.02	28.69	27.78	28.16	26.39
Polypropylene macro (0.25 %) + Polypropylene micro (0.25 %) + glass fibre (0.5%)	28	38.66	37.98	37.87	38.17	19.77
Steel plain (0.25%) + steel hooked (0.25%) + Polypropylene macro (0.25 %) + Polypropylene micro (0.25 %)	3	20.01	20.14	20.02	20.06	39.49
Steel plain (0.25%) + steel hooked (0.25%) + Polypropylene macro (0.25 %) + Polypropylene micro (0.25 %)	7	29.87	29.42	29.11	29.46	32.22
Steel plain (0.25%) + steel hooked (0.25%) + Polypropylene	28	40.95	39.98	39.55	40.16	26.05

macro (0.25 %) + Polypropylene micro (0.25 %)						
Steel hooked (0.5%) + glass fibre (0.5%)	3	19.42	19	19.31	19.24	33.79
Steel hooked (0.5%) + glass fibre (0.5	7	28.33	27.89	28.69	28.30	27.01
Steel hooked (0.5%) + glass fibre (0.5	28	38.15	38.22	39.25	38.54	20.96
Polypropylene macro (0.5 %) + steel hooked (0.5%)	3	19.43	18.22	18.41	18.69	29.97
Polypropylene macro (0.5 %) + steel hooked (0.5%)	7	27.13	27.58	27.89	27.53	23.56
Polypropylene macro (0.5 %) + steel hooked (0.5%)	28	38.21	38.74	37.74	38.23	20.01
Steel plain (0.5%) + glass fibre (0.5%)	3	14.77	15.52	15.48	15.25	6.05
Steel plain (0.5%) + glass fibre (0.5%)	7	22.41	21.98	22.78	22.39	0.49
Steel plain (0.5%) + glass fibre (0.5%)	28	34.87	32.22	34.55	33.88	6.34

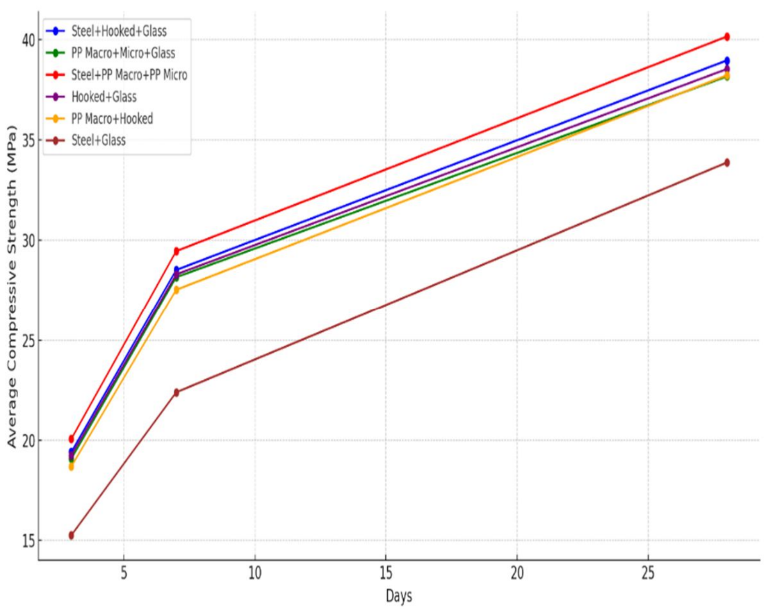

Fig.A.1 Graph of Compressive Strength vs. Curing Days for Hybrid Fibre Concrete

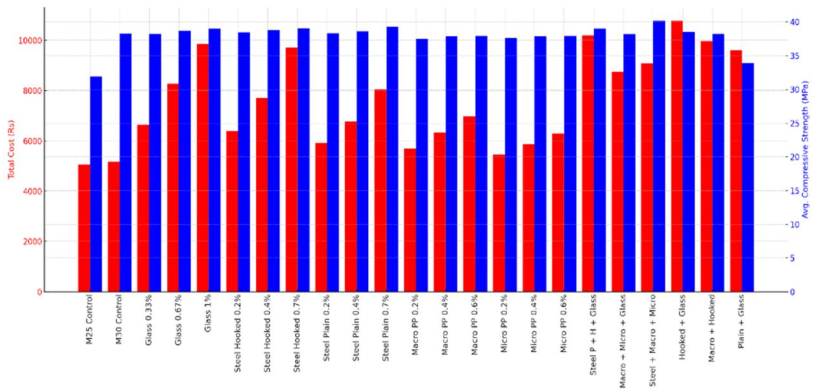

Fig.A.2 Comparison of Total Cost and Average Compressive Strength of Fibre-Reinforced Concrete Specimens

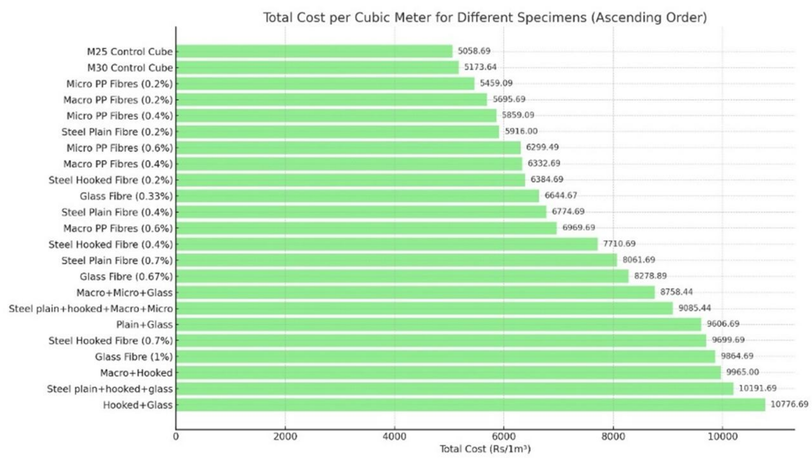

Fig.A.3 Total Cost per Cubic Meter for Different Specimens Arranged in Ascending Order

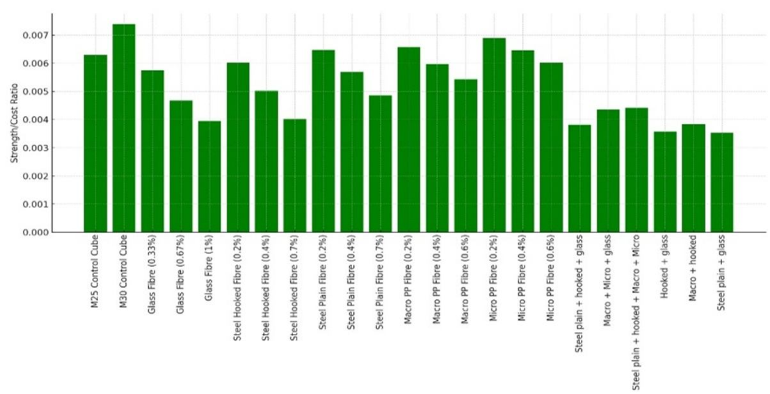

Fig.A.4 Strength-to-Cost Ratio of Concrete Specimens with Various Fibre Combinations

From the fig A.2 clearly illustrate the maximum compressive strength of 40.16 MPa was achieved using the hybrid combination of Steel plain (0.25%) + Steel hooked (0.25%) + Polypropylene macro (0.25%) + Polypropylene micro (0.25%), while the minimum compressive strength of 31.86 MPa was observed in the M25 control mix. In terms of cost, the highest cost was noted for the hybrid mix of Steel hooked (0.5%) + Glass fibre (0.5%) at ₹10,776.69 per m³, whereas the lowest cost was for the M25 control mix at ₹5,058.69 per m³. Considering both compressive strength and cost-effectiveness, the Steel Plain Fibre (0.2%) mix proved to be the most efficient, delivering a compressive strength of 38.31 MPa at a relatively low cost of ₹5,916 per m³, making it an optimal solution where high performance is needed within budget constraints.

The bar graphs in fig A.3 clearly illustrate the variation in total cost per cubic meter among different concrete specimens, both unmodified and reinforced with various fibers. The lowest costs are associated with control specimens and those containing micro or macro polypropylene fibers, indicating these options are more economical. As fiber content increases or combinations of different fibers are used, the cost tends to rise significantly. Notably, specimens combining steel hooked, steel plain, and glass fibers exhibit the highest costs, particularly the mix of steel hooked (0.5%) and glass fiber (0.5%), which tops the list. This suggests that while hybrid fiber combinations may offer enhanced mechanical properties, they come at a premium. Thus, the choice of fiber reinforcement should balance performance benefits with cost implications, depending on the specific application and budget constraints. The graph in fig .4 compares the strength-to-cost ratio of various concrete mixes, including M25 and M30 control cubes, individual fiber additions (glass, steel—plain and hooked, macro and micro polypropylene), and hybrid fiber combinations. Among all, steel hooked fiber (0.2%) show the highest cost efficiency. In terms of hybrid mixes, "Macro PP + Glass" exhibits the best strength-to-cost ratio, making it the most economical hybrid option. Overall, single-fiber mixes tend to be more cost-efficient, while hybrids offer enhanced performance with a trade-off in cost-effectiveness.

IV. CONCLUSION

Based on the result of test performed on the concrete specimen following conclusion can be drawn:

1) Hybrid fiber-reinforced concrete (HFRC) demonstrated a noticeable increase in compressive strength compared to conventional concrete, particularly at 28 days of curing.
2) The combination of steel hooked, steel plain, polypropylene (macro and micro), and glass fibers in optimal proportions led to improved strength performance due to the complementary behavior of each fiber type.
3) The best-performing hybrid mix—steel plain (0.25%) + steel hooked (0.25%) + polypropylene macro (0.25%) + polypropylene micro (0.25%)—achieved a maximum increase in compressive strength at 28 days over the control mix.
4) It was found that by using hybrid fibers, it is possible to achieve the compressive strength of M30 grade from an M25 grade base mix, however the cost reduction was not possible, on the contrary to some cases the cost was approximately double.
5) HFRC provides a sustainable construction solution, particularly by incorporating polypropylene and glass fibers, which can be derived from recycled or industrial waste materials.
6) Though hybrid fiber mixes are relatively costlier, they are suitable for applications where non cracking section and durability are essential. These include structures like water tanks where crack resistance is important, and industrial floors or workshop surfaces that require high abrasion resistance. In such cases, the performance benefits of hybrid fibers can justify the additional cost.
7) Despite improved strength, careful selection of fiber types and dosages is essential, as excessive or poorly balanced fiber content negatively impact cost.

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