

EXPERIMENTAL INVESTIGATION ON HIGH PERFORMANCE FIBRE REINFORCED CONCRETE WITH COPPER SLAG AND SILICA FUME

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Abstract: With rapid urbanization and technological advancement, significant modernization has taken place in concrete technology. Researchers have developed various types of advanced concrete by incorporating industrial waste materials to improve sustainability while enhancing the strength and durability of concrete. High Performance Fibre Reinforced Concrete (HPFRC) is one such innovative material that offers superior mechanical and durability characteristics compared to conventional concrete. The present study focuses on the experimental investigation of HPFRC incorporating silica fume and copper slag. Silica fume was used as a partial replacement of cement at proportions of 5%, 7.5%, and 10%, while copper slag was used as a partial replacement of fine aggregate at 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40%. Two types of fibre reinforced concrete mixes were prepared using Glass Fibre Reinforced Concrete (GFRC) and Polypropylene Fibre Reinforced Concrete (PPFRC). The performance of the developed mixes was evaluated through compressive strength and split tensile strength tests. The experimental results indicated a noticeable improvement in strength characteristics with the inclusion of silica fume, copper slag, and fibres. Among all the trial mixes, the optimum performance was achieved at 7.5% silica fume and 35% copper slag in Glass Fibre Reinforced Concrete (GFRC), which exhibited the highest compressive strength and split tensile strength. The findings demonstrate that the combined use of industrial by-products and fibres can produce sustainable, high-strength concrete suitable for modern structural applications.

Keywords: High Performance Concrete, Fibre Reinforced Concrete, Silica Fume, Copper Slag, Glass Fibre, Polypropylene Fibre, Compressive Strength, Split Tensile Strength, Sustainable Construction.

I. INTRODUCTION

Copper slag, a waste material generated during copper extraction and refining processes, has emerged as an effective alternative to natural sand in concrete. Due to its suitable particle size distribution, high density, and low water absorption, copper slag can improve workability and mechanical performance when used in optimum proportions.

conserving natural resources and reducing disposal problems associated with industrial waste.

Another significant development in concrete technology is the incorporation of fibres. Fibre Reinforced Concrete (FRC) contains discrete fibres uniformly distributed throughout the concrete matrix, which help in controlling micro-cracks, improving tensile strength, increasing toughness, and enhancing post-cracking behavior. Among various fibres, glass fibres and polypropylene fibres are commonly used because of their beneficial mechanical properties, corrosion resistance, and ease of mixing.

High Performance Fibre Reinforced Concrete (HPFRC) combines the advantages of mineral admixtures and fibre reinforcement to produce concrete with superior strength, ductility, and durability. In the present study, silica fume was used as a partial replacement of cement at 5%, 7.5%, and 10%, while copper slag was used as a partial replacement of fine aggregate at 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40%. Two categories of fibre reinforced concrete, namely Glass Fibre Reinforced Concrete (GFRC) and Polypropylene Fibre Reinforced Concrete (PPFRC), were prepared and tested. The performance of the developed concrete was evaluated based on compressive strength and split tensile strength.

II. Experimental investigations

A. Materials

Ordinary Portlandcement, In the present study, Birla super 53 grade OPC is used confirming to IS: 12269-1987.

Coarse Aggregate, They are hard and strong enough and free from the foreign material the aggregate used was as per IS 383:1970.

Fine Aggregate, Natural river sand which is locally available is selected for present study. And the sand is tested in laboratory to know the physical characteristic according to the applicable IS: 480.

Silica Fume and copper slag

Glass Fibre and Polypropylene Fibre

Water, Water is potable water and is free from the impurities

Superplasticizer, In this present study Glenium 8223 Superplasticizer is used which increases the workability of concrete without affecting the strength properties

B. Workability Test (Slump Cone Test)

Slump test is the most commonly used test for the measurement of workability of a fresh concrete both at site and laboratory. The apparatus required for conducting slump test are steel tamping rod of diameter 16 mm and length of 0.6 m with one end rounded, metallic plate and a metallic mould in the form of cone shape

C. Compressive Strength Test

The compressive test is carried out on concrete specimens to ensure that the concrete has developed the required target strength and the procedure of testing was done as per IS 516- 1959.



Fig. 1 COMPRESSIVE STRENGTH TESTING

D. Split Tensile Strength

Split-cylinder test is the standard test to find out the tensile strength of concrete. The cylinders of standard size 150 mm (dia) 300 mm (ht) are used in this test after curing. They were tested in Compression Testing Machine by placing it horizontally between the loading surfaces and the load is applied on longitudinal direction of the specimen. Strips of plywood are used to allow uniform distribution of load by placing them between the specimen and loading surfaces. The test procedures were carried as per IS 5816-1999. The split tensile strength is determined by the expression



Figure 2 SPLIT TENSILE STRENGTH TESTING

III. RESULTS AND DISCUSSIONS

A. Workability Test

% variations of Silica Fume	% variations of Copper Slag	Slumps of PPFRC in mm	Slumps of GFRC in mm
5%	0%	32	32
7.5%	0%	35	36
10%	0%	38	38

% variations of Silica Fume	% variations of Copper Slag	Slumps of PPFRC in mm	Slumps of GFRC in mm
5%	5%	32	32
7.5%	5%	38	40
10%	5%	38	39

% variations of Silica Fume	% variations of Copper Slag	Slumps of PPFRC in mm	Slumps of GFRC in mm
5%	10%	38	36
7.5%	10%	41	42

10%	10%	43	43
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% variations of Silica Fume	% variations of Copper Slag	Slumps of PPFRFC in mm	Slumps of GFRC in mm
5%	15%	40	38
7.5%	15%	42	44
10%	15%	43	43

% variations of Silica Fume	% variations of Copper Slag	Slumps of PPFRFC in mm	Slumps of GFRC in mm
5%	20%	45	44
7.5%	20%	47	48
10%	20%	47	47

% variations of Silica Fume	% variations of Copper Slag	Slumps of PPFRFC in mm	Slumps of GFRC in mm
5%	25%	44	44
7.5%	25%	47	48
10%	25%	46	47

% variations of Silica Fume	% variations of Copper Slag	Slumps of PPFRFC in mm	Slumps of GFRC in mm
5%	30%	41	43
7.5%	30%	43	42
10%	30%	40	42

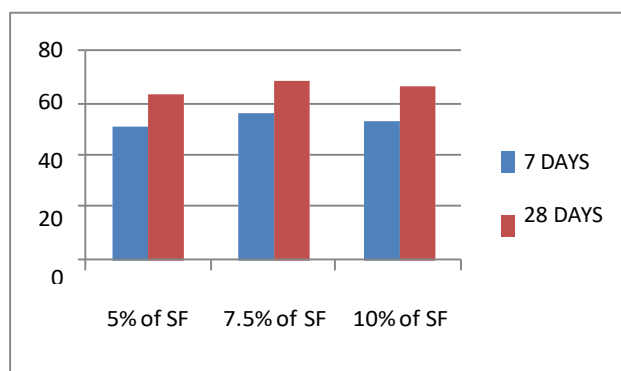
% variations of Silica Fume	% variations of Copper Slag	Slumps of PPFRFC in mm	Slumps of GFRC in mm
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5%	35%	41	43
7.5%	35%	44	46
10%	35%	40	42

% variations of Silica Fume	% variations of Copper Slag	Slumps of PPFR in mm	Slumps of GFRC in mm
5%	40%	46	46
7.5%	40%	48	50
10%	40%	45	44

B. Compressive Strength Test

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of GFRC (N/mm ²)	28days Compressive strength of GFRC (N/mm ²)
5%	0%	51.5	63.9
7.5%	0%	55.9	68.7
10%	0%	53.7	66.3



% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of GFRC in (N/mm ²)	28days Compressive strength of GFRC in (N/mm ²)
5%	5%	51.5	63.9
7.5%	5%	55.9	68.7
10%	5%	53.7	66.3

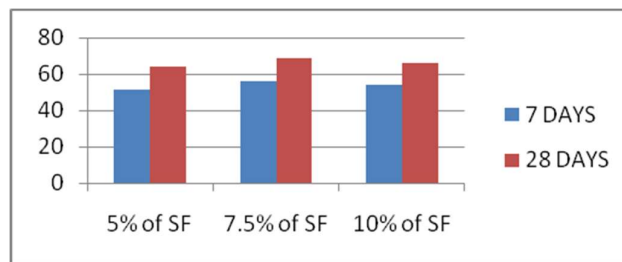


Figure 4 COMPRESSIVE STRENGTH OF GFRC for 5% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of GFRC in (N/mm ²)	28days Compressive strength of GFRC in (N/mm ²)
5%	10%	50.3	63.2
7.5%	10%	55.2	67.5
10%	10%	52.6	65.3

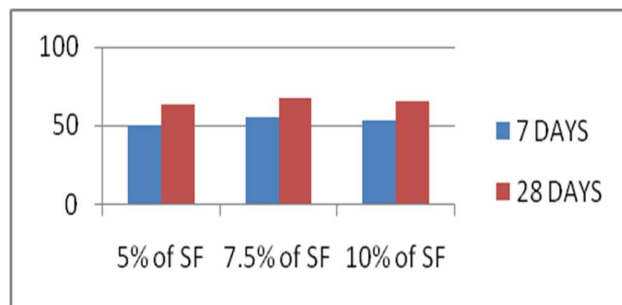


Figure 5 COMPRESSIVE STRENGTH OF GFRC for 10% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of GFRC in (N/mm ²)	28days Compressive strength of GFRC in (N/mm ²)
5%	15%	51.2	64
7.5%	15%	56.1	68.2
10%	15%	53.4	66.2

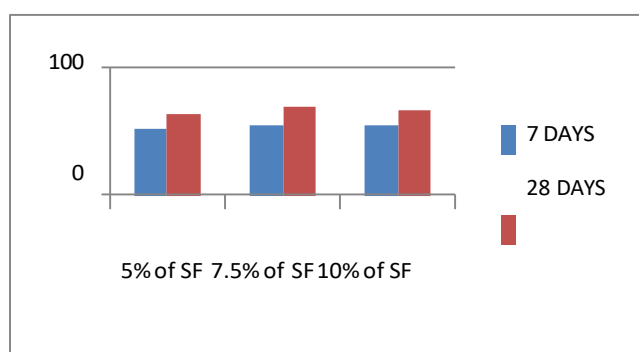


Figure 6 COMPRESSIVE STRENGTH OF GFRC for 15% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of GFRC in (N/mm ²)	28days Compressive strength of GFRC in (N/mm ²)
5%	20%	52.7	65.5
7.5%	20%	57.3	70.8
10%	20%	54.5	67.9

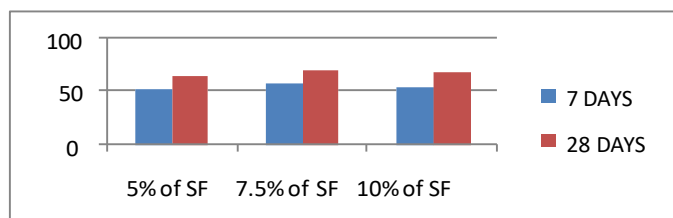


Figure 7 COMPRESSIVE STRENGTH OF GFRC for 20% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of GFRC in (N/mm ²)	28days Compressive strength of GFRC in (N/mm ²)
5%	25%	53.6	64.5
7.5%	25%	57.9	70.2
10%	25%	53.5	66.7

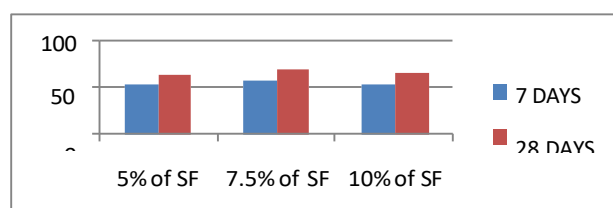


Figure 8 COMPRESSIVE STRENGTH OF GFRC for 25% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of GFRC in (N/mm ²)	28days Compressive strength of GFRC in (N/mm ²)
5%	30%	53.8	66.8
7.5%	30%	58.8	72.9
10%	30%	55.7	69.3

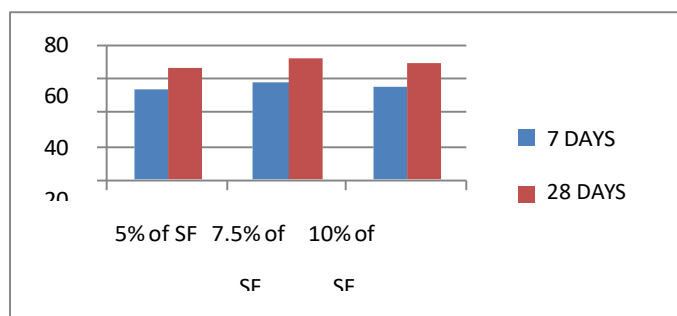


Figure 9 COMPRESSIVE STRENGTH OF GFRC for 30% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of GFRC in (N/mm ²)	28days Compressive strength of GFRC in (N/mm ²)
5%	35%	54	68.4
7.5%	35%	59.6	73.8
10%	35%	57.3	69.9

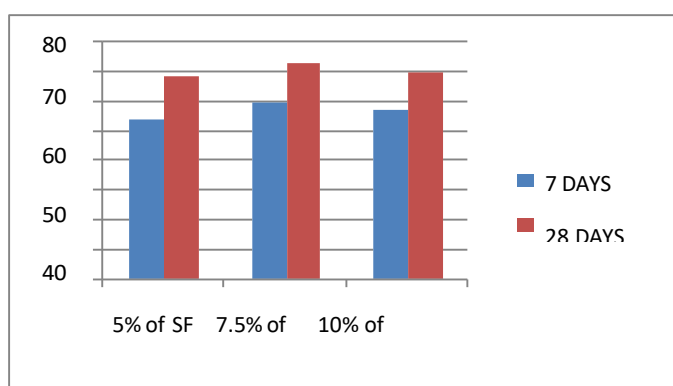


Figure 10 COMPRESSIVE STRENGTH OF GFRC for 35% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of GFRC in (N/mm ²)	28days Compressive strength of GFRC in (N/mm ²)
5%	40%	56.3	68.4
7.5%	40%	62.9	73
10%	40%	59.8	71

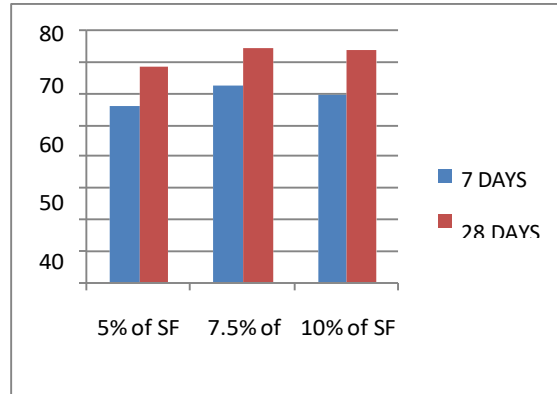


Figure 11 COMPRESSIVE STRENGTH OF GFRC for 40% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of PPFRC in (N/mm ²)	28days Compressive strength of PPFRC in (N/mm ²)
5%	0%	50.4	61.4
7.5%	0%	53.9	66.5
10%	0%	52.9	65.4

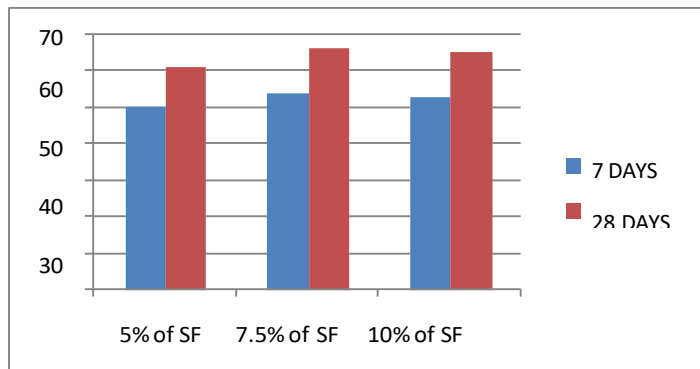


Figure 12 COMPRESSIVE STRENGTH OF PPFRC for 0% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of PPFRC in (N/mm ²)	28days Compressive strength of PPFRC in (N/mm ²)
5%	0%	50.4	61.4
7.5%	0%	53.9	66.5
10%	0%	52.9	65.4

5%	5%	50.8	61.9
7.5%	5%	54.3	67.1
10%	5%	54.2	66.1

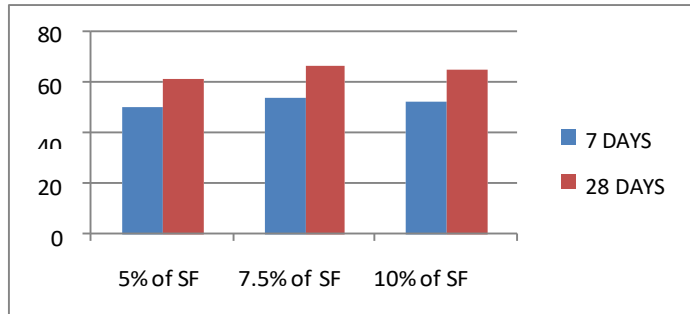


Figure 13 COMPRESSIVE STRENGTH OF PPFR for 5% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of PPFR in (N/mm²)	28days Compressive strength of PPFR in (N/mm²)
5%	10%	48.2	61.2
7.5%	10%	53.4	66.3
10%	10%	51.9	64.8

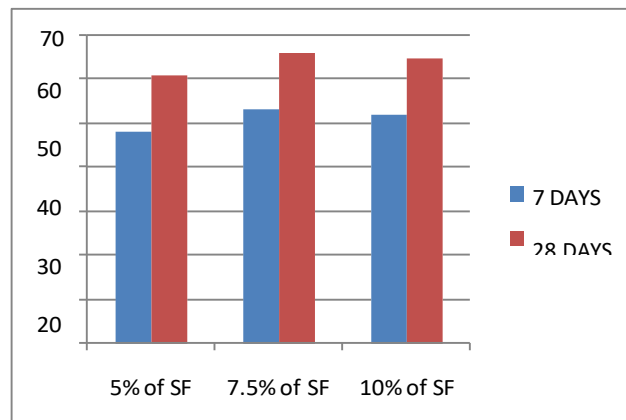


Figure 14 COMPRESSIVE STRENGTH OF PPFR for 10% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of PPFRC in (N/mm ²)	28days Compressive strength of PPFRC in (N/mm ²)
5%	15%	49.2	62
7.5%	15%	54.1	66.7
10%	15%	51.3	64.6

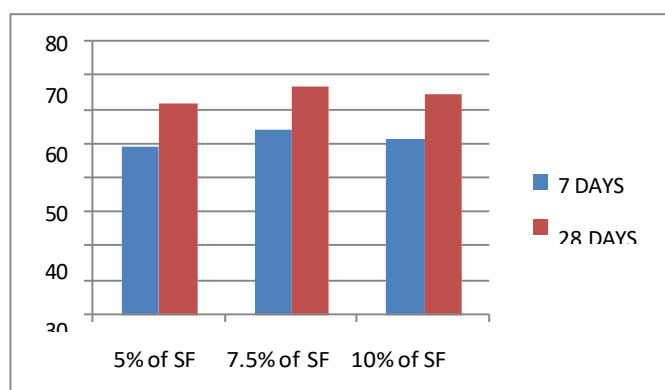


Figure 15 COMPRESSIVE STRENGTH OF PPFRC for 15% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of PPFRC in (N/mm ²)	28days Compressive strength of PPFRC in (N/mm ²)
5%	20%	50.7	63.1
7.5%	20%	56.1	68.2
10%	20%	52.3	65.6

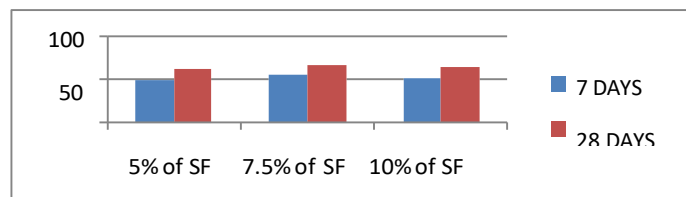


Figure 16 COMPRESSIVE STRENGTH OF PPFRC for 20% of SF

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of PPFRC in (N/mm ²)	28days Compressive strength of PPFRC in (N/mm ²)
5%	25%	51.4	63.1
7.5%	25%	56.1	68.4
10%	25%	51.7	64.2

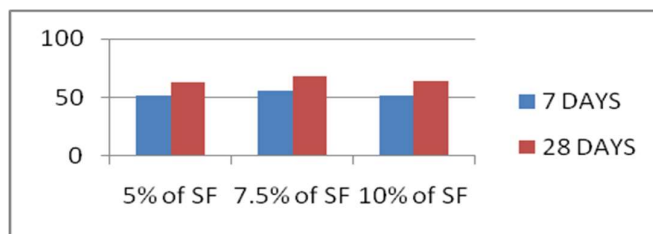


Figure 17 COMPRESSIVE STRENGTH OF PPFRC for 25% of CS

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of PPFRC in (N/mm ²)	28days Compressive strength of PPFRC in (N/mm ²)
5%	30%	52.1	64.8
7.5%	30%	56.4	70.4
10%	30%	53.9	66.9

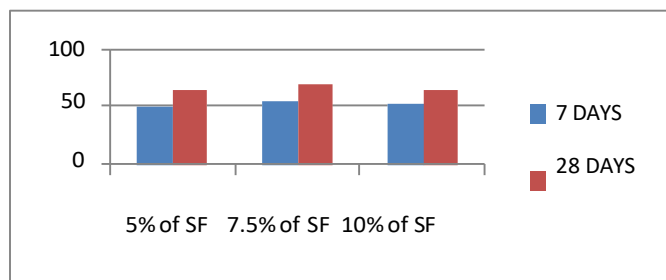


Figure 18 COMPRESSIVE STRENGTH OF PPFRC for 30% of SF

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of PPFRC in (N/mm ²)	28days Compressive strength of PPFRC in (N/mm ²)
5%	35%	55	66.6
7.5%	35%	57.1	72.9
10%	35%	56.3	67.9

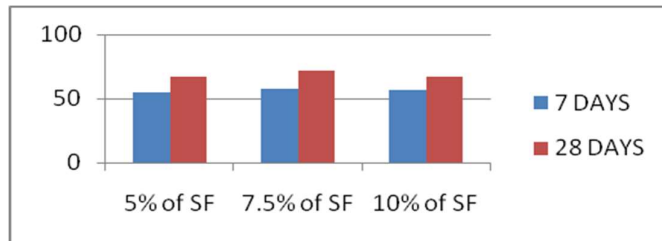


Figure 19 COMPRESSIVE STRENGTH OF PPFRC for 35% of SF

% variations of Silica Fume	% variations of Copper Slag	7days Compressive strength of PPFRC in (N/mm ²)	28days Compressive strength of PPFRC in (N/mm ²)
5%	40%	55.3	67.9
7.5%	40%	59.9	72.4
10%	40%	61.3	68.7

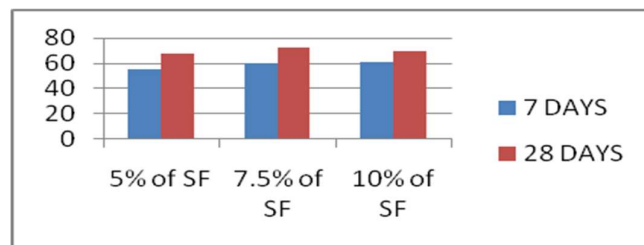


Figure 20 COMPRESSIVE STRENGTH OF PPFRC for 40% of SF

a. SPLIT TENSILE STRENGTH

% variations of Silica Fume	% variations of Copper Slag	7days Split tensile strength of GFRC in (N/mm ²)	7days Split Tensile strength of PPFRC in (N/mm ²)
5%	0%	4.01	3.80
7.5%	0%	4.27	3.90
10%	0%	4.13	3.90

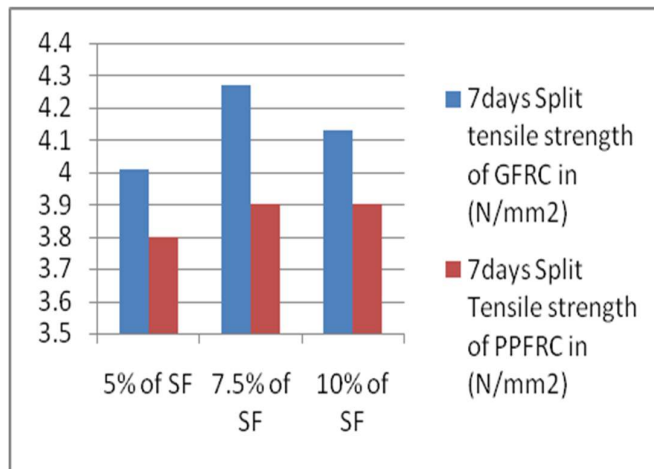


Figure 21 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 0% CS

% variations of Silica Fume	% variations of Copper Slag	7days Split tensile strength of GFRC in (N/mm ²)	7days Split Tensile strength of PPFRC in (N/mm ²)
5%	5%	4.01	3.70
7.5%	5%	4.11	3.90
10%	5%	4.12	3.80

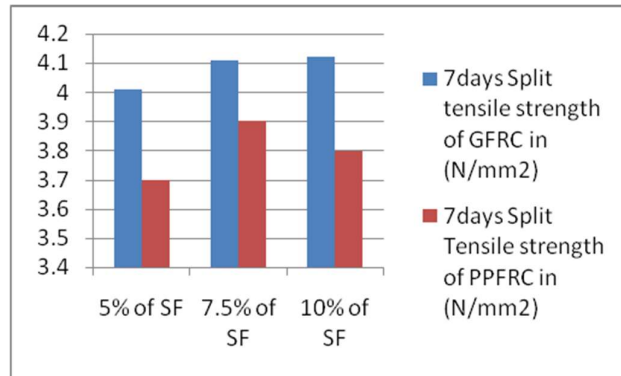


Figure 22 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 5% CS

% variations of Silica Fume	% variations of Copper Slag	7days Split tensile strength of GFRC in (N/mm ²)	7days Split Tensile strength of PPFRC in (N/mm ²)
5%	10%	4.25	3.90
7.5%	10%	4.80	4.10
10%	10%	4.13	4.10

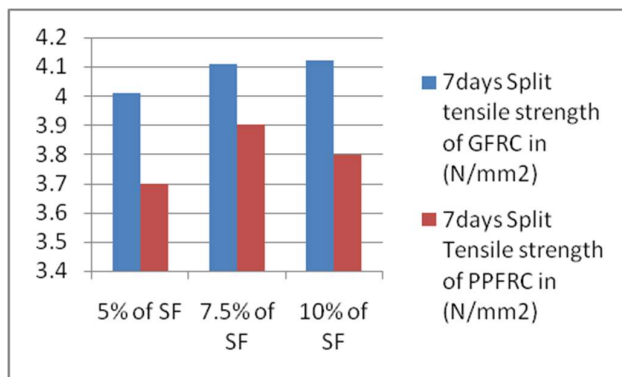


figure 23 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 10% CS

% variations of Silica Fume	% variations of Copper Slag	7days Split tensile strength of GFRC in (N/mm ²)	7days Split Tensile strength of PPFRC in (N/mm ²)
5%	15%	4.25	3.85
7.5%	15%	4.90	4.10
10%	15%	4.10	4.10

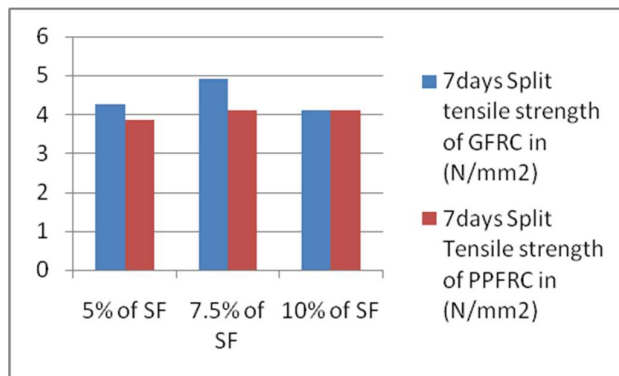


Figure 24 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 15% CS

% variations of Silica Fume	% variations of Copper Slag	7days Split tensile strength of GFRC in (N/mm ²)	7days Split Tensile strength of PPFRC in (N/mm ²)
5%	20%	4.42	3.92
7.5%	20%	4.90	4.25
10%	20%	4.90	4.25

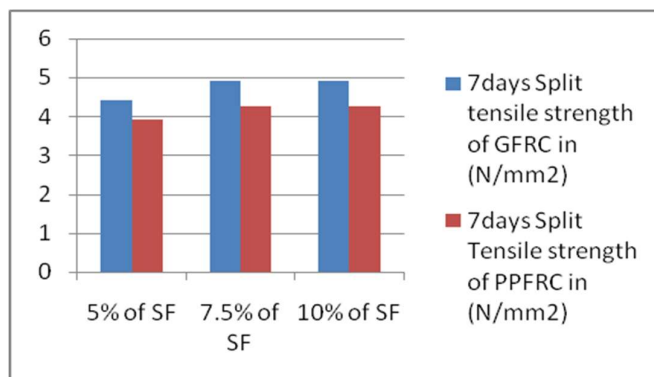


Figure 25 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 20% CS

% variations of Silica Fume	% variations of Copper Slag	7days Split tensile strength of GFRC in (N/mm ²)	7days Split Tensile strength of PPFRC in (N/mm ²)
5%	25%	4.42	3.92
7.5%	25%	4.90	4.25
10%	25%	4.90	4.25

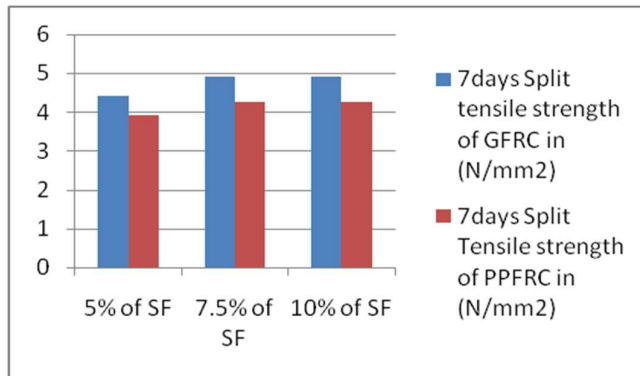


Figure 26 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 25% CS

% variations of Silica Fume	% variations of Copper Slag	7days Split tensile strength of GFRC in (N/mm ²)	7days Split Tensile strength of PPFRC in (N/mm ²)
5%	30%	4.65	4.23
7.5%	30%	5.01	4.60
10%	30%	5.01	4.75

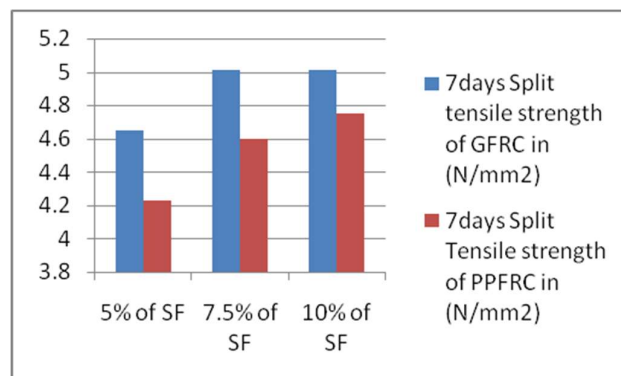


Figure 27 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 30% CS

% variations of Silica Fume	% variations of Copper Slag	7days Split tensile strength of GFRC in (N/mm ²)	7days Split Tensile strength of PPFRC in (N/mm ²)
5%	35%	5.20	4.90
7.5%	35%	6.10	5.65
10%	35%	5.90	5.85

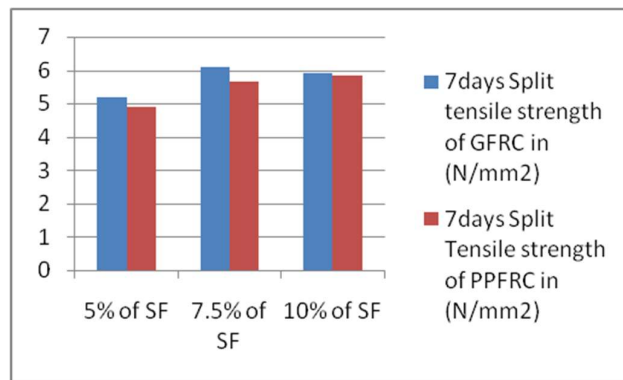


Figure 28 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 35% CS

% variations of Silica Fume	% variations of Copper Slag	7days Split tensile strength of GFRC in (N/mm ²)	7days Split Tensile strength of PPFRC in (N/mm ²)
5%	40%	5.30	5.10
7.5%	40%	6.40	5.85
10%	40%	5.90	5.35

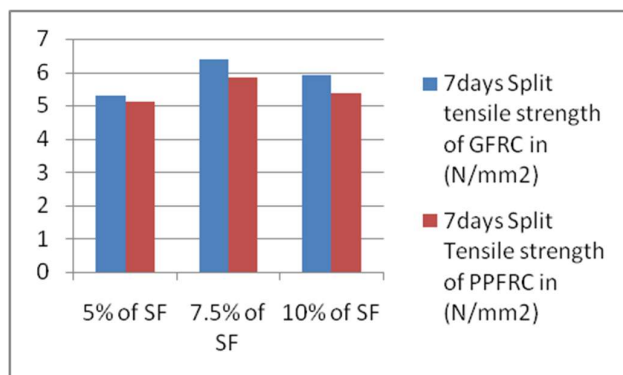


Figure 29 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 40% CS

% variations of Silica Fume	% variations of Copper Slag	28days Split tensile strength of GFRC in (N/mm ²)	28 days Split Tensile strength of PPFRC in (N/mm ²)
5%	0%	4.70	3.75
7.5%	0%	4.90	4.10
10%	0%	4.60	3.95

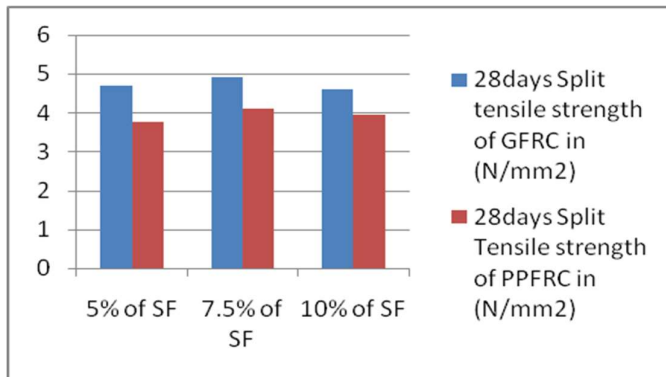


Figure 30 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 0% CS

% variations of Silica Fume	% variations of Copper Slag	7days Split tensile strength of GFRC in (N/mm ²)	7days Split Tensile strength of PPFRC in (N/mm ²)
5%	5%	4.70	3.75
7.5%	5%	4.90	4.10
10%	5%	4.60	3.95

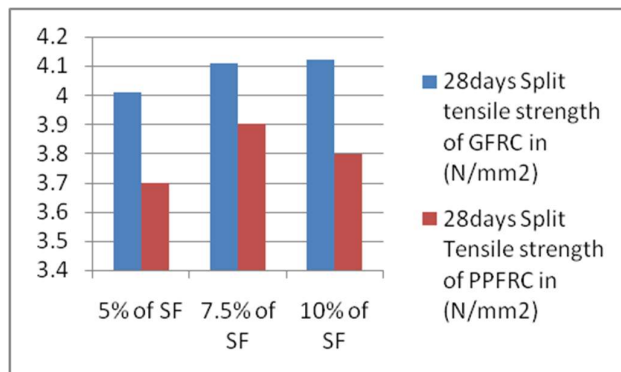


Figure 31 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 5% CS

% variations of Silica Fume	% variations of Copper Slag	7days Split tensile strength of GFRC in (N/mm ²)	7days Split Tensile strength of PPFRC in (N/mm ²)
5%	10%	4.85	4.10
7.5%	10%	5.10	4.30
10%	10%	4.62	4.30

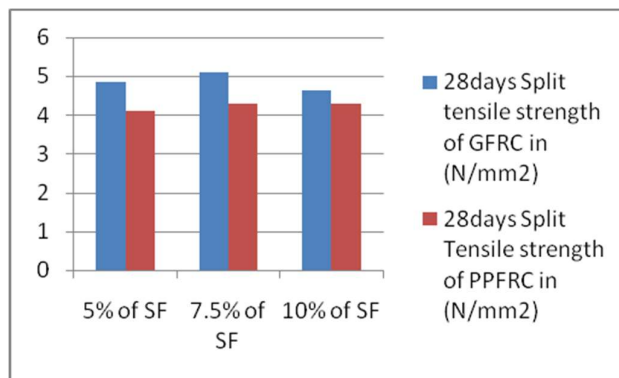


Figure 32 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 10% CS

% variations of Silica Fume	% variations of Copper Slag	28days Split tensile strength of GFRC in (N/mm ²)	28days Split Tensile strength of PPFRC in (N/mm ²)
5%	15%	4.95	4.30
7.5%	15%	5.30	4.50
10%	15%	4.76	4.40

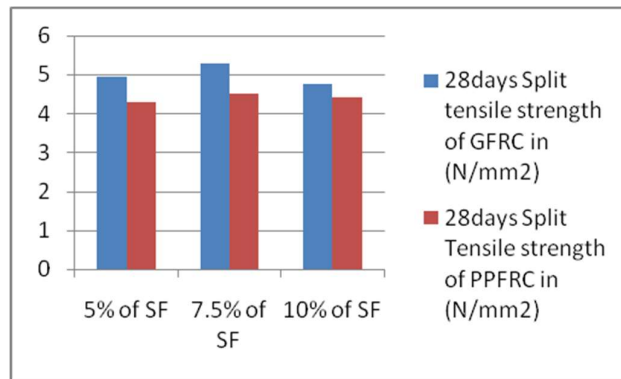


Figure 33 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 15% CS

% variations of Silica Fume	% variations of Copper Slag	28days Split tensile strength of GFRC in (N/mm²)	28days Split Tensile strength of PPFRC in (N/mm²)
5%	20%	4.95	4.30
7.5%	20%	5.30	4.50
10%	20%	4.76	4.40

Figure 34 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 20% CS

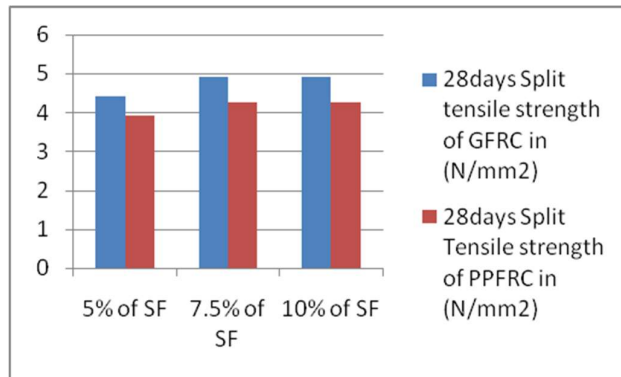


Figure 34 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 20% CS

% variations of Silica Fume	% variations of Copper Slag	28days Split tensile strength of GFRC in (N/mm²)	28days Split Tensile strength of PPFRC in (N/mm²)
5%	25%	5.30	4.90

7.5%	25%	5.90	5.00
10%	25%	5.10	4.70

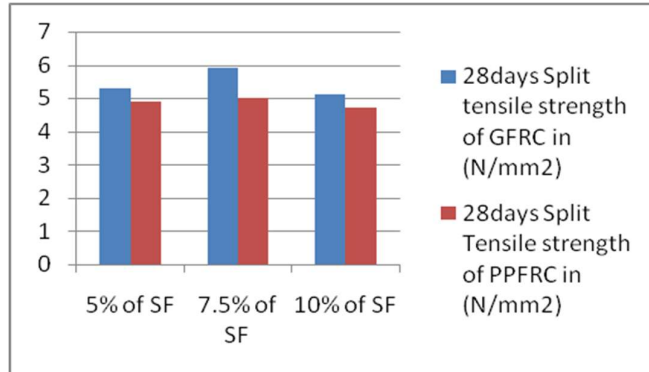


Figure 35 SPLIT TENSILE STRENGTH OF GFRC & PPFRFRC for 25% CS

% variations of Silica Fume	% variations of Copper Slag	28days Split tensile strength of GFRC in (N/mm²)	28days Split Tensile strength of PPFRFRC in (N/mm²)
5%	30%	5.40	4.85
7.5%	30%	5.80	5.10
10%	30%	5.20	4.90

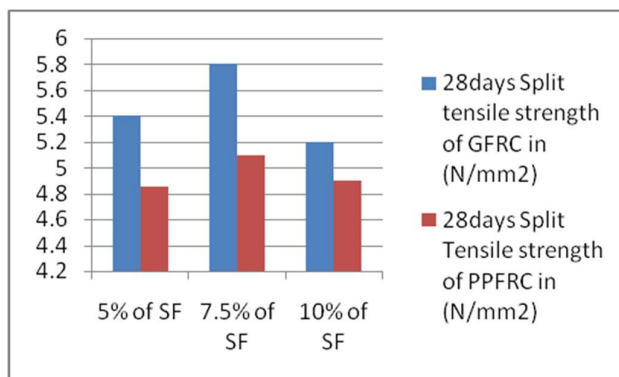


Figure 36 SPLIT TENSILE STRENGTH OF GFRC & PPFRFRC for 30% CS

% variations of Silica Fume	% variations of Copper Slag	28days Split tensile strength of GFRC in (N/mm ²)	28days Split Tensile strength of PPFRC in (N/mm ²)
5%	35%	5.90	5.20
7.5%	35%	6.90	6.20
10%	35%	6.20	6.35

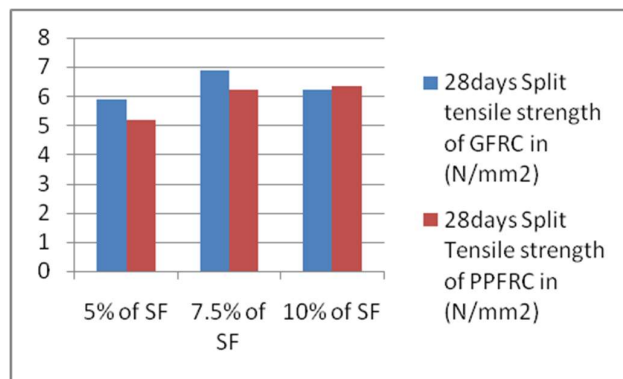


figure 37 SPLIT TENSILE STRENGTH OF GFRC & PPFRC for 35% CS

% variations of Silica Fume	% variations of Copper Slag	28days Split tensile strength of GFRC in (N/mm ²)	28days Split Tensile strength of PPFRC in (N/mm ²)
5%	40%	5.95	5.20
7.5%	40%	6.90	6.50
10%	40%	6.20	6.35

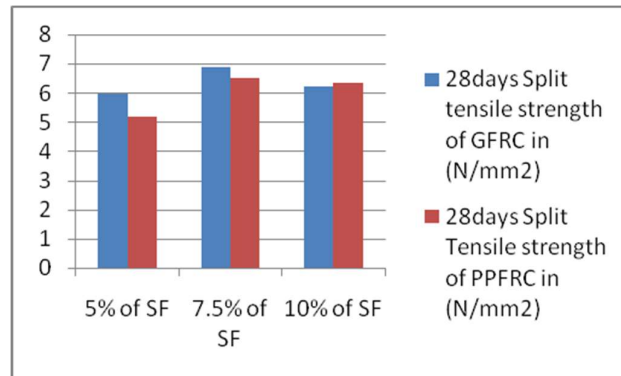


Figure 38 SPLIT TENSILE STRENGTH OF GFRC & PPFRc for 40% CS

IV. CONCLUSION

1. The effect of silica fume and copper slag on the fresh characteristics of HPFRc was evaluated using the slump cone test. The workability of HPFRc decreases as the replacement levels of silica fume and copper slag increase. The reduction in slump is mainly attributed to the porous texture of copper slag. In addition, the presence of fibres increases entrapped air voids within the mix, which further lowers workability.
2. The maximum compressive strength for both Glass Fibre Reinforced Concrete (GFRC) and Polypropylene Fibre Reinforced Concrete (PPFRc) was achieved at the optimum mix proportion containing 7.5% silica fume as partial replacement of cement and 35% copper slag as partial replacement of fine aggregate. This enhancement in strength can be attributed to the pozzolanic reactivity and micro-filling effect of silica fume, which densifies the cement matrix, along with the improved particle packing and better interfacial bonding provided by copper slag. The combined action of these materials resulted in a more compact and homogeneous concrete matrix, thereby significantly improving the compressive strength performance of both fibre reinforced concrete mixes.
3. The maximum split tensile strength for both Glass Fibre Reinforced Concrete (GFRC) and Polypropylene Fibre Reinforced Concrete (PPFRc) was achieved at the optimum mix combination containing 7.5% silica fume as partial replacement of cement and 35% copper slag as partial replacement of fine aggregate. This improvement is mainly attributed to the presence of fibres, which act as effective crack arresters by bridging micro-cracks and restricting their initiation and propagation under tensile loading. The fibres enhance stress transfer across cracked sections and delay sudden failure, thereby increasing the energy absorption capacity and post-cracking resistance of the concrete. In addition, the incorporation of fibres imparts greater ductility to the concrete matrix, which was clearly observed during the splitting tensile test through the gradual and controlled failure of the cylinder specimens rather than abrupt brittle fracture. The combined effect of silica fume, copper slag, and fibre reinforcement resulted in a stronger, tougher, and more ductile composite with superior split tensile performance.

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Conflicts of Interest: Authors must declare all conflicts of interest. If there are no conflicts of interest, it should also be stated as such: "The authors declare that they have no conflicts of interest to report regarding the present study."

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