Strength Characteristics of Slurry Infiltrated Hybrid Fibrous Ferrocement

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Abstract : Main objective of this experimentation programme was to study the strength characteristics of slurry infiltrated hybrid fibrous ferrocement (SIHFF). The different types of fibres used in this experimentation programme were steel fibres (SF), carbon fibres (CF), basalt fibres (BF), galvanized iron fibres (GIF) and polypropylene fibres (PPF). The different combinations of hybrid fibres used in this experimentation programme were (SF+CF), (SF+BF), (SF+GIF) and (SF+PPF) and percentage of fibres used is (1%+1%). The monofibres were added at 2% by volume fraction. The strength characteristics studied in this paper include compressive strength, flexural strength and flexural toughness factor.

***IndexTerms* -** Compressive strength; flexural strength; flexural toughness factor; slurry infiltrated hybrid fibrous ferrocement.

I. INTRODUCTION

Concrete is widely used man made construction material in the civil engineering field all over the world. However concrete has many deficiencies such as low tensile strength, low post cracking capacity, brittleness, low ductility and low impact strength. To overcome these deficiencies discontinuous, discrete, uniformly dispersed suitable fibres are added to the normal concrete. The purpose of addition of short fibres is to improve the tensile strength and impact-resistance and to reduce the brittleness of concrete. A composite can be termed as hybrid, if two or more types of fibres are rationally combined in a common matrix to produce a composite that benefits from each of the individual's fibres and exhibits a synergetic response. Debonding and pull out of the fibre require more energy absorption, resulting in a substantial increase in the toughness and fracture resistance of the materials to the cyclic and dynamic loads. In 1979 a new material, slurry-infiltrated fibre concrete (SIFCON), was introduced by Dr. David Lankard of the Lankard Materials Laboratory (LML) in Columbus, Ohio. Dr. Lankard had done some pioneer work in the development of the material, as well as some applications using the material in the paving and metal fabrication industries. Ferrocement is a type of thin-wall reinforced concrete commonly constructed of hydraulic-cement mortar reinforced with closely spaced layers of continuous and relatively small wire mesh. The recent trend in ferrocement has been rightly summarized by Prof. A. E Naaman "The history of ferrocement as a modern construction material is longer than that of reinforced concrete, prestressed concrete and steel. Its path for the future as a laminated cementitious composite combining advanced cement based matrices, high performance reinforcing meshes and fibres and new construction techniques, promises to be as bright". Ferrocement is environmentally sound technology since it is found to be ideal for rehabilitation and re-strengthening of existing structures. The ferrocement construction reduces labour cost, improves quality of the material, reduces or eliminates repair and maintenance by reducing the use of raw materials. The present experimental study was planned to evaluate compressive strength, flexural strength and flexural toughness factor of slurry infiltrated hybrid fibrous ferrocement.

II. EXPERIMENTAL PROGRAM

The main objective of this investigation was to find out the structural behavior of slurry infiltrated hybrid fibrous ferrocement and its application as a structural material. The study was basically oriented towards the usage of different hybrid fibre combinations such as (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF). The percentage of hybrid fibres adopted in the experimentation was (1%+1%). Welded mesh and chicken mesh were also used. The strength characteristics such as compressive strength, flexural strength and flexural toughness factors of slurry infiltrated hybrid fibrous ferrocement were studied in detail.

2.1 MATERIALS:

Cement: 43 grade ordinary Portland cement (OPC) was used in this experimentation programme with specific gravity 3.15 and conforming to IS: 8112-1989.
Fine aggregate: Locally available river sand was used in this experimentation programme with specific gravity 2.60 and belongs to zone II of IS: 383-1970.
Water: Water which is free from acids, oils, alkalis and other impurities was used.
Steel fibres: In the present work flat crimped steel fibres of length 20mm were used. Steel fibres were obtained from Ryan International Pune.
Carbon fibres: In the present work carbon fibres of length 18 mm were used. Carbon fibres were obtained from Nickunj Enterprises Pvt. Ltd. Mumbai.
Basalt fibres: In the present work basalt fibres of length 18 mm were used. Basalt fibres were obtained from Nickunj Enterprises Pvt. Ltd. Mumbai.
Galvanized iron fibres: Round GI wire of 1mm diameter was cut to the required length of 20 mm and were used as fibres.
Polypropylene fibres: In the present work polypropylene fibre of length 20mm were used. Polypropylene fibres were obtained from Bajaj Reinforcements Nagpur.
Welded mesh: Welded mesh used for the experimentation was having a rectangular opening of 30 mm x 35 mm with 20 gauges.
Chicken mesh: Chicken mesh used for the experimentation was having a hexagonal opening with 0.5 mm diameter.

The used steel, basalt, carbon, polypropylene and galvanized iron fibres are as shown in the figure 1.

				
Steel fibre	Basalt fibre	Carbon fibre	Polypropylene fibre	Galvanized Iron fibre

Figure 1: Types of Fibres used

2.2 CASTING:

Cement – sand slurry was prepared with a mix proportion of 1:1 with a w/c ratio of 0.35. In the present experimentation the different hybrid fibre combinations used are (SF+BF), (SF+CF), (SF+PPF), and (SF+GIF). The percentage of hybrid fibres and mono fibres adopted in the experimentation was (1%+1%) and 2% by volume fraction respectively. In the present experimental programme the mix proportion was fixed after studying the literature review and also after several trail mixes. The trial mix study has suggested to fix the mix proportion as 1:1 for the present research work with a w/c ratio of 0.35. The required size of welded mesh and chicken mesh were first cut according to the mould sizes. For compressive strength 130 mm x 130 mm x 130 mm size cube shape, for flexural strength 480 mm x 90 mm size rectangular shape cages were prepared for casting the specimens. The chicken mesh was tied to the welded mesh using binding wires at regular intervals. Initially required quantity of cement and sand were taken and mixed. Then the known quantity of fibres were added to the dry cement-sand mortar and once again mixed properly in dry condition and then required water was added. The prepared cages were placed in the moulds which were oiled. Initially a small quantity of slurry (10-15 mm) was poured into the mould and then the respective cages were placed in the mould and then slurry was filled into the mould up to the brim level and was lightly compacted manually as well as using the table vibrator. Then the moulds were covered with wet gunny bags for 24 hours. After 24 hours, the specimens were de-moulded and kept in water for 28 days curing. After 28 days of curing, they were taken out of water and were tested for their respective strengths. The welded mesh and chicken mesh for cubes and beams are as shown in the Figure 2.

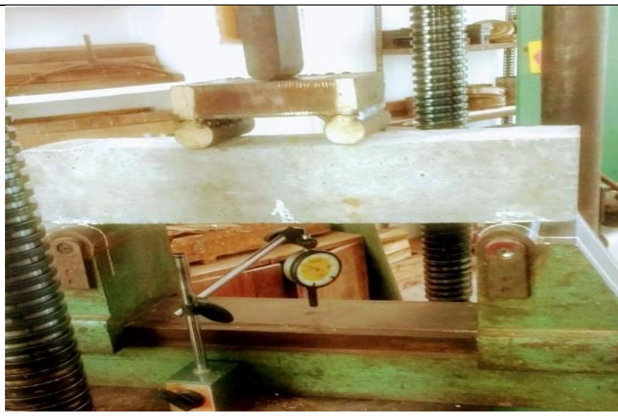
	
For cube specimens	For beam specimens

Figure 2: Welded and chicken mesh cages for different specimens

2.3 TEST SET UP AND TESTING:

The cubes and beam specimens were tested as per IS 516:1959 to obtain compressive and shear strengths respectively. The specimens were tested in compression testing machine of capacity 1000kN. The testing of specimens can be seen in Figure 3.

Compression test



Flexural test

Figure 3: Testing of specimens

III. DISCUSSION OF TEST RESULTS

3.1 Compressive strength:

Table 1 gives the compressive strength test results of slurry infiltrated hybrid fibrous ferrocement with different combination of fibres. Figure 4 gives the graphical representation of variation of compressive strength. Test results clearly show that the compressive strength of slurry infiltrated hybrid fibrous ferrocement with different combinations of hybrid fibres are higher as compared to the respective slurry infiltrated mono fibrous ferrocement. The compressive strength of slurry infiltrated hybrid fibrous ferrocement for (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) are found to be 49.63 MPa, 48.30 MPa, 47.85 MPa and 46.81 MPa respectively (Table 1). The percentage increase in the compressive strength of slurry infiltrated hybrid fibrous ferrocement for (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) as compared to slurry infiltrated mono fibrous ferrocement for CF, GIF, BF and PPF are found to be 2.45%, 2.52%, 3.19% and 2.58% respectively. And also the percentage increase in the compressive strength of slurry infiltrated hybrid fibrous ferrocement with the combination of fibres (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) are found to be 12.41%, 9.40%, 8.38% and 6.02% respectively as compared to slurry infiltrated ferrocement

The reason for increase in the compressive strength of slurry infiltrated hybrid fibrous ferrocement is that under the axial load the cracks occur in the micro structure of concrete and fibres limit the formation and growth of the cracks by preventing pinching force at crack tips. Also, hybrid fibres will act synergistically and low modulus fibres and high modulus fibres come into role during initial stage of cracking and subsequent stages of cracking respectively. This reduces the crack tip stress concentration there by blocking the forward propagation of the crack and even diverting the path of the crack. This blocking and diverting of the crack allows the hybrid fibrous ferrocement to withstand additional loads thereby increasing its compressive strength over the mono fibrous ferrocement and as well as reference ferrocement.

Thus it can be concluded that the compressive strength of slurry infiltrated hybrid fibrous ferrocement is better or superior as compared to slurry infiltrated mono fibrous ferrocement and slurry infiltrated ferrocement. And it can also be concluded that slurry infiltrated hybrid fibrous ferrocement with combination of (SF+CF) exhibits higher compressive strength as compared to other hybrid fibre combination of (SF+GIF), (SF+BF) and (SF+PPF).

3.2 Flexural strength:

Table 1 gives the flexural strength test results of slurry infiltrated hybrid fibrous ferrocement with different combination of fibres. Figure 5 gives the graphical representation of variation of flexural strength. It is observed that the flexural strength of slurry infiltrated hybrid fibrous ferrocement with different combinations of hybrid fibres is higher as compared to the respective slurry infiltrated mono fibrous ferrocement. The flexural strength of slurry infiltrated hybrid fibrous ferrocement for (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) are found to be 11.11 MPa, 9.85 MPa, 8.41 MPa and 7.32 MPa respectively (Table 1). The percentage increase in the flexural strength of slurry infiltrated hybrid fibrous ferrocement for (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) as compared to slurry infiltrated mono fibrous ferrocement for CF, GIF, BF and PPF are found to be 5.10%, 10.05%, 13.18% and 15.09% respectively. And also the percentage increase in the flexural strength of slurry infiltrated hybrid fibrous ferrocement with the combination of fibres (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) are found to be 103.85%, 80.73%, 54.31% and 34.31% respectively as compared to slurry infiltrated ferrocement

The increase in the flexural strength of slurry infiltrated hybrid fibrous ferrocement is more as compared to the slurry infiltrated mono fibrous ferrocement because of the availability of both low modulus fibres and high modulus fibres and they coming into role during initial stage of cracking and subsequent stages of cracking respectively. The hybrid fibres show synergistic effect in which one fibre is efficient in micro cracking level and other fibre at macro cracking level, thereby increasing its flexural strength over the mono fibrous ferrocement and as well as reference ferrocement.

Thus it can be concluded that the flexural strength of slurry infiltrated hybrid fibrous ferrocement is better or superior as compared to slurry infiltrated mono fibrous ferrocement and slurry infiltrated ferrocement. And it can also be concluded that slurry infiltrated hybrid fibrous ferrocement with combination of (SF+CF) exhibits higher flexural strength as compared to other hybrid fibre combination of (SF+GIF), (SF+BF) and (SF+PPF).

3.2 Flexural toughness factor test results:

Table 1 gives the flexural toughness factor test results of slurry infiltrated hybrid fibrous ferrocement with different combination of fibres. Figure 6 gives the graphical representation of variation of flexural toughness factor. It is observed that the flexural toughness factor of slurry infiltrated hybrid fibrous ferrocement with different combinations of hybrid fibres is higher as compared to the respective slurry infiltrated mono fibrous ferrocement. The flexural toughness factor of slurry infiltrated hybrid fibrous ferrocement for (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) are found to be 1.804 N/mm^2, 1.008 N/mm^2, 0.648 N/mm^2 and 0.549 N/mm^2 respectively (Table 1). The percentage increase in the flexural toughness factor of slurry infiltrated hybrid fibrous ferrocement for (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) as compared to slurry infiltrated mono fibrous ferrocement for CF, GIF, BF and PPF are found to be 28.03%, 42.77%, 28.57% and 26.49% respectively. And also the percentage increase in the flexural toughness factor of slurry infiltrated hybrid fibrous ferrocement with the combination of fibres (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) are found to be 596.52%, 289.18%, 150.19% and 111.19% respectively as compared to slurry infiltrated ferrocement.

The increase in the flexural toughness factor of slurry infiltrated hybrid fibrous ferrocement is more as compared to the slurry infiltrated mono fibrous ferrocement because of the availability of both low modulus fibres and high modulus fibres and they coming into role during initial stage of cracking and subsequent stages of cracking respectively. The hybrid fibres show synergistic effect in which one fibre is efficient in micro cracking level and other fibre at macro cracking level, thereby increasing its flexural toughness factor over the mono fibrous ferrocement and as well as reference ferrocement.

Thus it can be concluded that the flexural toughness factor of slurry infiltrated hybrid fibrous ferrocement is better or superior as compared to slurry infiltrated mono fibrous ferrocement and slurry infiltrated ferrocement. And it can also be concluded that slurry infiltrated hybrid fibrous ferrocement with combination of (SF+CF) exhibits higher flexural toughness factor as compared to other hybrid fibre combination of (SF+GIF), (SF+BF) and (SF+PPF).

Table 1: Compressive strength, flexural strength and flexural toughness factor test results

Sl.No.	Description of concrete	Compressive strength (N/mm^2)	Flexural strength (N/mm^2)	Flexural toughness (N-m)	Flexural toughness factor (N/mm^2)
1	SF+CF	49.63	11.11	11.995	1.804
2	SF+GIF	48.30	9.85	6.703	1.008
3	SF+BF	47.85	8.41	4.307	0.648
4	SF+PPF	46.81	7.32	3.648	0.549
5	SF	48.00	9.73	6.485	0.975
6	CF	48.44	10.57	9.372	1.409
7	GIF	47.11	8.95	4.695	0.706
8	BF	46.37	7.43	3.353	0.504
9	PPF	45.63	6.36	2.885	0.434
10	WM+CM	44.15	5.45	1.723	0.259
11	CM	43.11	3.85	0.843	0.127

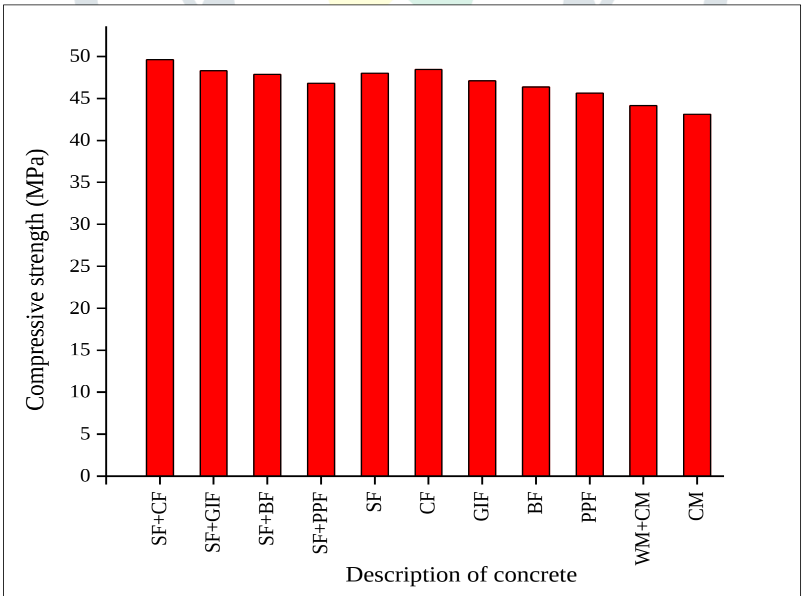


Figure 4: Variation of compressive strength

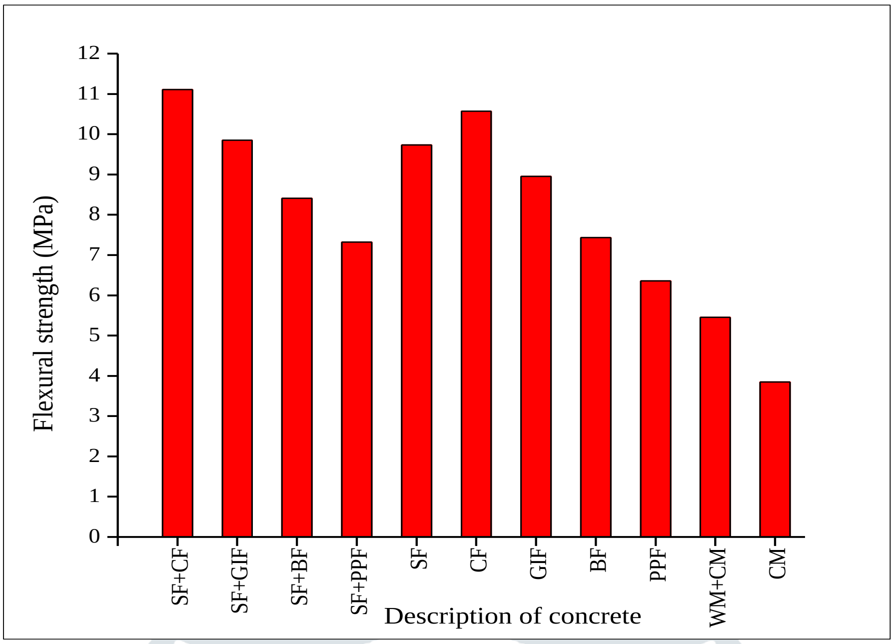


Figure 5: Variation of flexural strength

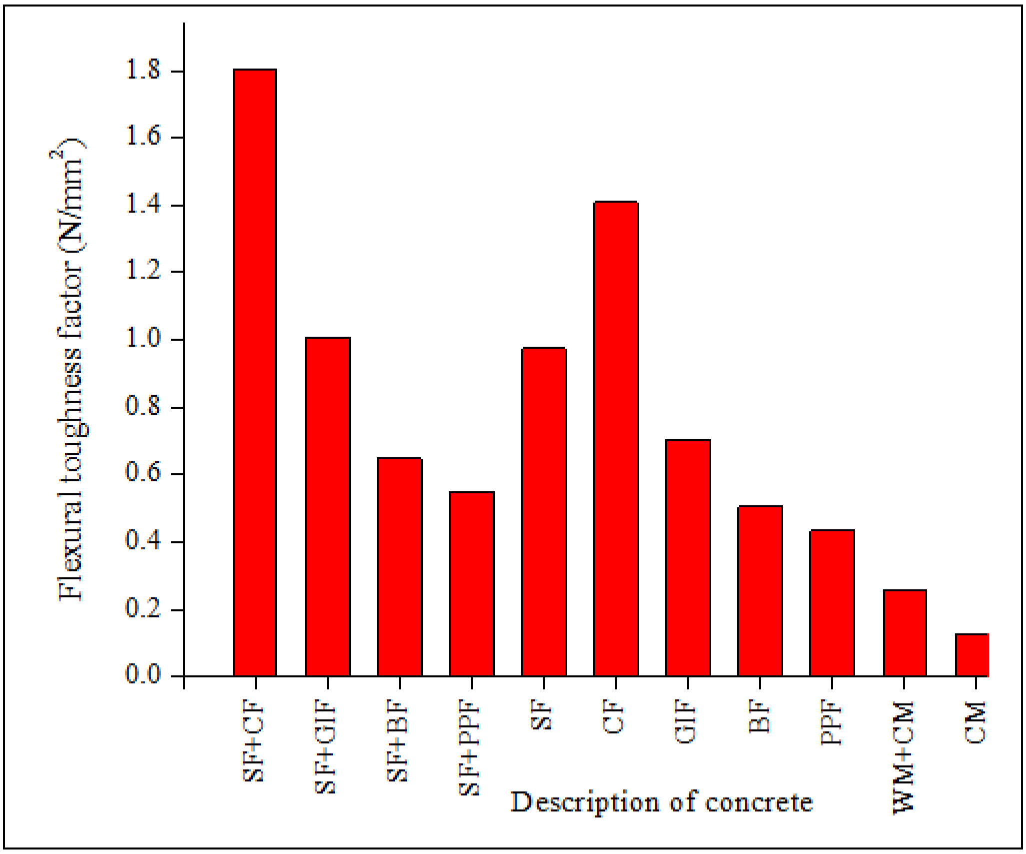


Figure 6: Variation of flexural toughness factor

IV. CONCLUSIONS

Following conclusions are made from the present experimental work:

1. Compressive strength of slurry infiltrated hybrid fibrous ferrocement is better or superior as compared to slurry infiltrated mono fibrous ferrocement and slurry infiltrated ferrocement. The percentage increase in the compressive strength of slurry infiltrated hybrid fibrous ferrocement with the combination of fibres (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) are 12.41%, 9.40%, 8.38% and 6.02% respectively. Also slurry infiltrated hybrid fibrous ferrocement with (SF+CF) exhibits higher compressive strength as compared to hybrid fibre combination (SF+GIF), (SF+BF) and (SF+PPF).

2. Flexural strength of slurry infiltrated hybrid fibrous ferrocement is better or superior as compared to slurry infiltrated mono fibrous ferrocement and slurry infiltrated ferrocement. The percentage increase in the flexural strength of slurry infiltrated hybrid fibrous ferrocement with the combination of fibres (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) are 103.85%, 80.73%, 54.31% and

34.31% respectively. Also slurry infiltrated hybrid fibrous ferrocement with (SF+CF) exhibits higher flexural strength as compared to hybrid fibre combination (SF+GIF), (SF+BF) and (SF+PPF).

3. Flexural toughness factor of slurry infiltrated hybrid fibrous ferrocement is better or superior as compared to slurry infiltrated mono fibrous ferrocement and slurry infiltrated ferrocement. The percentage increase in the flexural toughness factor of slurry infiltrated hybrid fibrous ferrocement with the combination of fibres (SF+CF), (SF+GIF), (SF+BF) and (SF+PPF) are 596.52%, 289.18%, 150.19% and 111.19% respectively. Also slurry infiltrated hybrid fibrous ferrocement with (SF+CF) exhibits higher flexural toughness factor as compared to hybrid fibre combination (SF+GIF), (SF+BF) and (SF+PPF).

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