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Performance of High Strength Basalt Fiber Reinforced Metakaolin Concrete

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ABSTRACT

The present work deals with the results of experimental investigations on high strength M60 basalt fiber reinforced metakaolin concrete. Effect of these fibers on various strengths of concrete are studied. Fiber content varied from 0.5 to 1.5% at an interval of 0.5 by weight of cement. Various strengths considered for investigation are compressive strength, flexural strength, split tensile, and bond strength. Cube of size 100 mm for compressive strength, beams of size 500 mm × 100 mm × 100 mm for flexural strength were cast. All the specimens were water cured up 7 and 28 days and tested subsequently. The workability is measured with the slump cone test. A comparison of results of high strength basalt fiber reinforced metakaolin concrete with that of modified concrete showed the significant improvements in the results of various strengths.

Keywords: *Metakaolin, basalt fiber, composites, HSBFRMC, fiber volume fraction, strengths*

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INTRODUCTION

Revolution in the infrastructure industry is because of the versatility of concrete. Its plastic nature in fresh state and other mechanical properties in hardened state have made it most widely used construction material. But concrete also suffers from some inherent drawbacks such as low tensile strength, brittleness, unstable crack propagation, etc. These drawbacks has led to extensive research on concrete to improve its many structural properties, such as better resistance to cracking, spalling, fatigue, impact and improved compressive, shear, flexural, bond strengths, and ductility.

Fiber reinforcement is one of the best alternatives to enhance the mechanical properties of plain cement concrete. A brief review of literature on fiber reinforced concrete (FRC) is given by Balaguru and Shah [1] including guidelines for design, mixing, placing, and finishing FRC. Hannant [2] has presented the basic theoretical and simplified principles of FRC subjected to various states of stress. Basalt fibers are used because of features such as high temperature resistant, good chemical stability, good mechanical properties and high tensile strength, etc. The improvement in various strengths of steel fiber reinforced concrete (SFRC) has been studied by various research workers with low fiber volume fractions of fibers [3–7].

EXPERIMENTAL PROGRAMME

Mix design of M60 grade of concrete is carried out using ACI method [8]. Ordinary Portland cement of 53 grade is used confirming to IS 12269 [9]. Fine aggregate of fineness modulus 3.17 and specific gravity

2.63 are used along with the coarse aggregate of fineness modulus 6.87 and specific gravity 2.77 confirming to IS 383 [10]. Metakaolin (a mineral admixture) is used as a cement replacement at a constant rate of 10% by weight of cement. Fiber content varies from 0.5 to 1.5% by weight of cement. The properties of Basalt fiber and metakaolin are given in Tables I and II, respectively. Cubes of size 100 mm×100mm for compressive and bond strength, beams of size 100 mm×100 mm×500mm for flexural strength, cylinders of 300 mm length and 100 mm diameter for split tensile strength are cast. All the specimens are water cured and tested after 7 and 28 days.

The workability is measured with the slump cone test. The various strengths studied in this investigation are compressive strength, flexural strength, flexural shear strength, split tensile strength, and bond strength at 7 and 28 days respectively. A comparison of results of high strength basalt fiber reinforced metakaolin concrete with that of modified concrete (concrete made by replacing cement with metakaolin, by 10% by weight of cement) showed the significant enhancement in various strengths. Figures 1–4 show the graphical representation of variation of these different strengths with respect to percentage fiber volume fraction at 7 and 28 days, respectively.

Table I Physical Properties of Basalt fibers.

Sr. no.	Properties	Value
1	Diameter	6 μm
2	Length of fiber	12 mm
3	Appearance	Golden brown
4	Tensile strength	4.84 GPa
5	Modulus of elasticity	89 GPa
6	Specific gravity	2.8–3.0

Table II. Properties of Metakaolin Used.

Chemical Properties	
SiO_2	50–55%
Al_2O_3	38–42%
CaO	1–3%
TiO_2	0.8–1.2
Na_2O	<1%
Fe_2O_3	0.2–0.5
K_2O	<1%
MnO	<0.5%
MgO	<0.1%
Loss on ignition	Max 1.5%
Physical Properties	
Bulk density (g/cc)	0.5461 (When packed)
Color	White
Specific gravity	2.30

TESTS CONDUCTED ON CONCRETE

In present study cube compressive strength, flexural test on beams, split test, pullout test on normal concrete, and high strength basalt fiber reinforced metakaolin concrete (HSBFRMC) with varying fraction were carried out with constant metakaolin content on number of samples. The experimental setup for various tests and there results are described below.

Compressive Strength

Cube compression tests were performed on standard cubes of size 100 mm × 100 mm × 100 mm after 7 and 28 days curing as per IS 516:1959 [11].

The compressive strength of specimen was calculated by the following formula:

$f_{cu} = P_c/A$ (1)

where P_c is the failure load in compression (kN) and A is the loaded area of cube (mm^2).

Table III. Compressive Strength of Modified and HSBFRMC Concrete (MPa).

Sr. no.	Fiber content (%)	Compressive strength (f_{cu}) (Mpa)	
		7 days	28 days
1	0.0	37.83	59.44
2	0.5	38.45	61.00
3	1.0	40.33	61.67
4	1.5	39.00	60.33

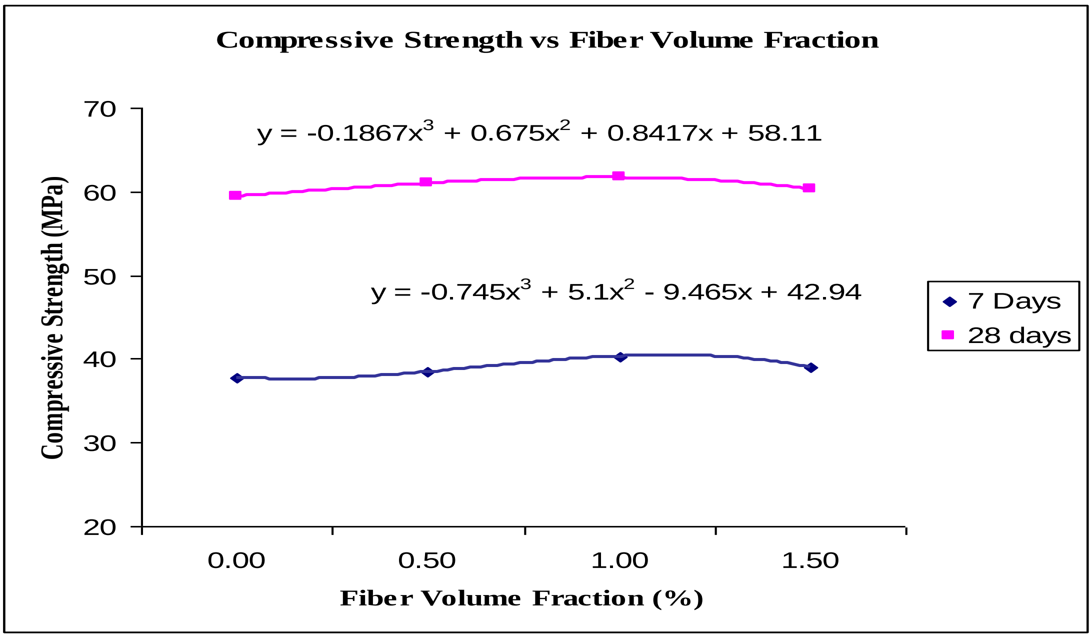

Fig. 1 Variation of Compressive Strength at the Age of 7 and 28 days With Respect to Percentage Fiber Volume Fraction.

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Split Tensile Strength

The test is carried out on cylinder by splitting along its middle plane parallel to the edges by applying the compressive load to opposite edges.

$f_t = 2P_l/\pi LD$ (2)

where f_t is the tensile strength (Mpa), P_l the load at failure, (N), L the length of cylinder (mm), and D is the diameter of cylinder (mm).

Table IV. Split Tensile Strength on Cylinder (Mpa).

Sr. no.	Fiber content(%)	Split tensile strength(Mpa)	
		7 days	28 days
01	0.0	1.76	2.21
02	0.5	1.80	2.34
03	1.0	1.64	2.13
04	1.5	1.78	2.32

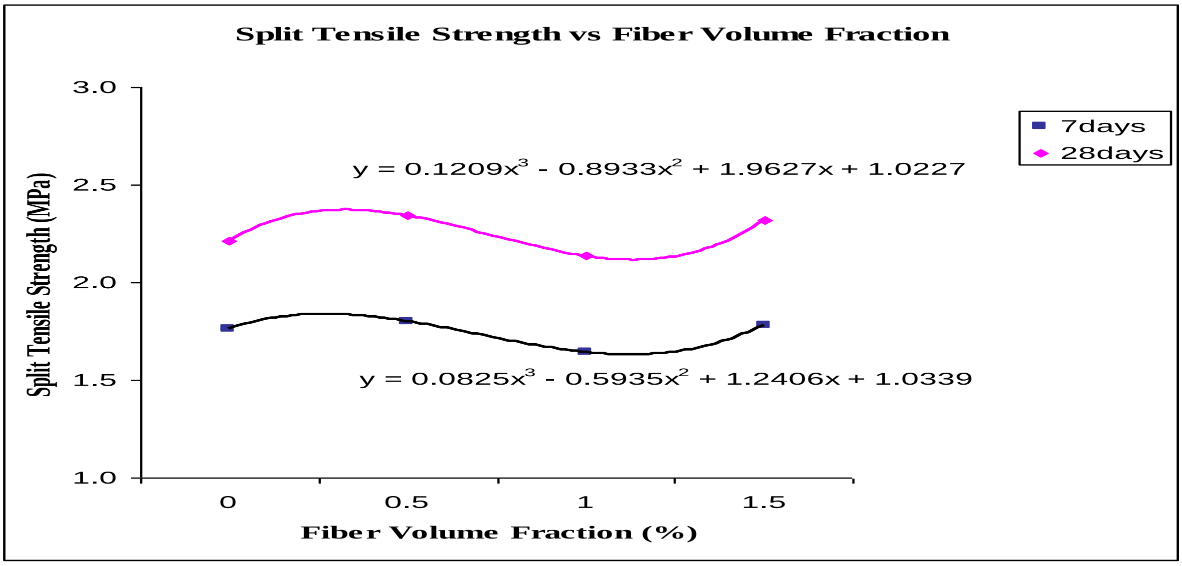

Fig. 2 Variation of Split Tensile Strength at the Age of 7 and 28 days with Respect to Percentage Fiber Volume Fraction.

Flexural Strength

Flexural strength test is performed on beam specimen according to IS 516:1959 [11]. Standard beams of size 100 mm × 100 mm × 500 mm were supported symmetrically over a span of 400 mm and subjected to two points loading till failure of the specimen.

$f_{cr} = P_f L/bd^2$ (3)

where f_{cr} is the flexural strength (Mpa), P_f the central load (N), L the span of beam (mm), b the width of beam (mm), the d is the depth of beam (mm).

Table V. Flexural Strength of Beam (MPa).

Sr. no.	Fiber content (%)	Flexural strength (MPa)	
		7 days	28 days
1	0	1.47	1.9
2	0.5	1.57	2.24
3	1.0	1.66	2.46
4	1.5	1.72	2.59

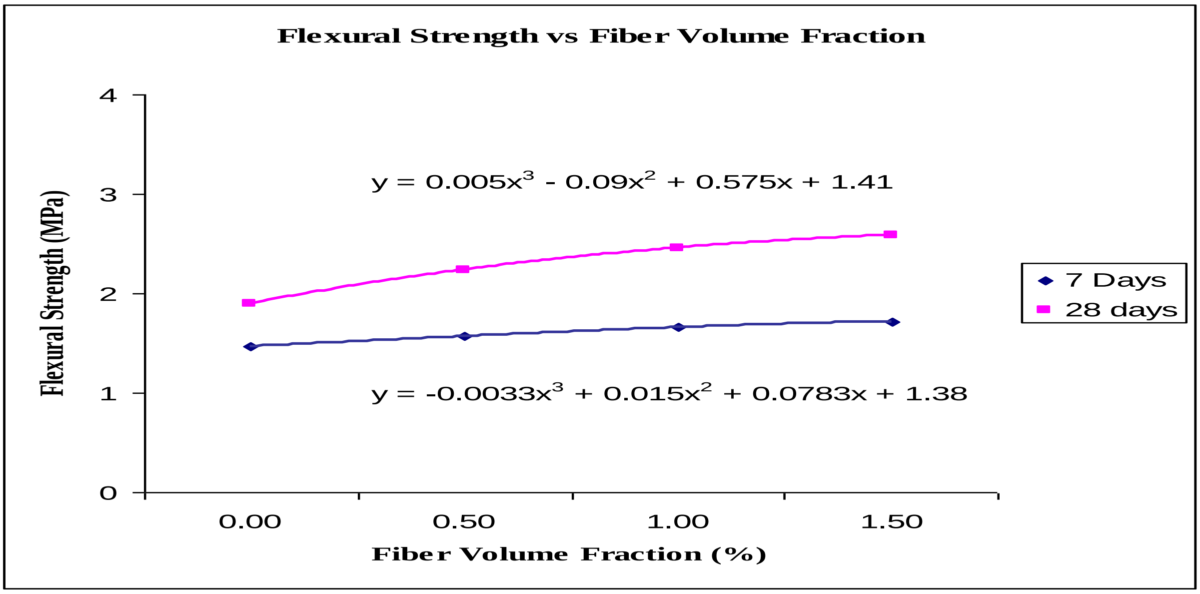

Fig. 3 Variation of Flexural Strength at the Age of 7 and 28 days With Respect to Percentage Fiber Volume Fraction.

Bond Strength (Pull Out Test)

The specimen was casted according to ASTM standard C 234-91a [12] with 12 mm diameter tor steel rod embedded in 100 mm × 100 mm × 100 mm concrete cube casted and compacted on vibrating table. The verticality of 12 mm embedded tor steel rod is ensured by supporting till concrete hardens.

$\tau_{bd} = P/\pi dL$ (4)

where τ_{bd} is the bond strength, (N/mm^2), P the pull out force (N), D the diameter of rod embedded in concrete cube, 12 mm, and$L$ is the length of rod embedded in concrete, 100 mm.

Table VI. Bond Strength (MPa).

Sr. no.	Fiber volume fraction V_f (%)	Max. pull out force (N)		Bond strength (τ_{bd}) (MPa)	
		7 days	**28 days**	**7 days**	**28 days**
1.	0.0	23.34	30.44	6.19	8.07
2.	0.5	25.10	32	6.66	8.49
3.	1.0	26.88	35.41	7.13	9.39
4.	1.5	30.77	36.66	8.16	9.72

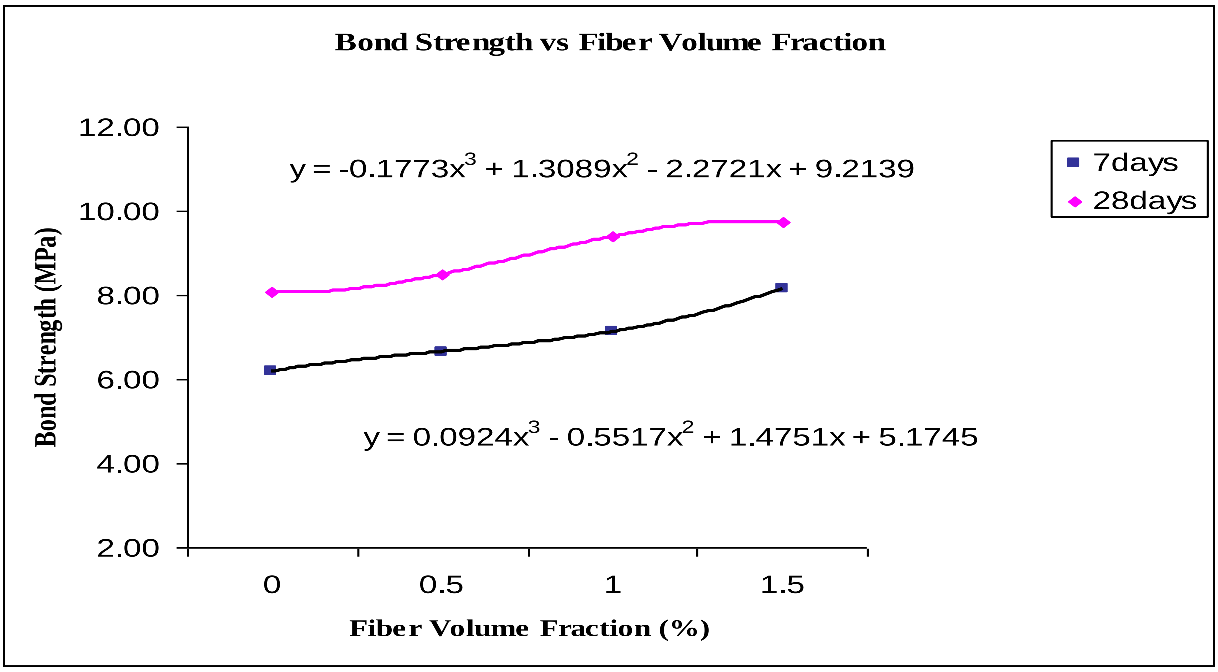

Fig. 4 Variation of Bond Strength at the Age of 7 and 28 days With Respect to Percentage Fiber Volume Fraction.

RESULTS AND DISCUSSION

1. Results of compressive strength are shown in Table (III). Marginal enhancement in compressive strength is seen as the percentage of fiber content increases. Cracks occur in microstructure of concrete and fibers reduce the crack formation and propagation. Also metakaolin improves the microstructure of concrete.

2. From Table (IV), the maximum increase in split tensile strength is 6.81% for 7 days and 5.88% for HSBFRMC at 28 days. The split tensile strength decreases up to 1.0% fiber content. This variation in split tensile strength may due to degree of compaction,

mix proportion, size of aggregate, loading rate during test procedure, etc.

3. From above Table (V), it is observed that the flexural strength increases with increase in fiber content up to 1.5%. The maximum values at 7 and 28 days are1.72 and 2.59, respectively. Thus, there is enhancement in flexural strength of concrete from 6.8 to 17.00% at 7 days and from 17.89 to 36.31% at 28 days.

4. From Table (VI), it is observed that bond strength has increased marginally with the addition of fibers over modified concrete. There is continuous enhancement in bond strength upto 1.5% fiber content.

CONCLUSIONS

1. The maximum gain in strength of concrete is found to depend upon the amount of fiber content. The optimum fiber content to impart maximum gain in various strengths varies with type of the strengths.
2. The optimum percentage fiber volume fraction for compressive strength, flexural strength and split tensile strength is 1.0% while for bond strength is 1.5%. Satisfactory workability was maintained with increasing volume fraction of fibers by using super-plasticizer.
3. With increasing fiber content, mode of failure was changed from brittle to ductile failure when subjected to compression and bending.
4. The following Table (VII) shows the optimum fiber content for various strengths.

Table VII The Optimum Fiber Content for Various Strengths.

Strength (MPa)	**Basalt fiber content (%)**	**Max. value of strength (Mpa)**	**Percentage variation of strength over normal concrete (%)**
Compressive strength	1.0	61.67	3.75
Flexural strength	1.5	2.59	36.31
Split tensile strength	0.5	2.34	5.88
Bond strength	1.5	9.72	20.44

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