Journal of Civil Engineering and Environmental Technology
Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 2, Number 12; April-June, 2015 pp. 1-6

http://www.krishisanskriti.org/jceet.html

Study the Effects of Short Basalt Fibers on Mechanical Properties of Concrete

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Abstract—*The objective of this paper is to investigate and compare the compressive, splitting tensile and flexural strength of basalt fiber reinforced concrete with plain M30 grade concrete. Fiber reinforced concrete is a most widely used solution for improving tensile and flexural strength of concrete. Various types of fibers such as steel, polypropylene, glass and polyester are generally used in concrete. In this research, the effect of inclusion of basalt fibers on the compressive, flexural and splitting tensile strength of fiber reinforced concrete was studied. The basalt fiber used in the present study has a diameter of 13 μm and a length of 12 mm. Based on the laboratory experiment on basalt fiber reinforced concrete, cube, beam and cylindrical specimens have been designed with basalt fiber reinforced concrete containing 0%,1.0%,1.5% and 2.0% of basalt fibers by the weight of cement.The compressive and split tensile strengths are carried out on cubes and cylinders by using Compressive Testing Machine(CTM) and flexural strength of basalt fiber reinforced concrete beam were tested with the help of Universal Testing Machine (UTM) under two-point loading. For each percentage of fiber total three cubes and three beams and three cylinders were casted to take average results. Finally comparative results are shown for each percentage of basalt fibers and the results show that, basalt reinforcement enhanced the split and tensile strength of the concrete.*

1. INTRODUCTION

Basalt fiber is an inorganic fiber material. It is an all-natural material and originates from volcanic rock. Basalt rock is melted at high-temperature (1450 ° C) and rapidly drawn into a continuous fiber. It then can be chopped into various lengths. Its color can vary between brown, gold or gray. The basic characteristics of Basalt materials are high-temperature resistance, high corrosion resistance, resistance to acids and alkalis, high strength and thermal stability. Basalt materials can be used as a reinforcing composite material for the construction industry, specifically as a less expensive alternative to carbon fiber. In addition to high specific strength, high specific modulus, Basalt Fiber also has excellent temperature resistance, anti-radiation, thermal and sound insulation, anti-compression strength and high shear strength, high availability, and good cost performance. It is found in nature as an inorganic non-metal material, and is a new basic material and high-tech fiber that can satisfy the demand for the development of basic infrastructures.

Basalt fiber is a "multi-performance" fiber. For example, it is resistant to alkalis and acids; it is thermally, electrically and sound insulated; its tensile strength can be greater than large-tow carbon fiber, its elongation is better than small tow carbon fiber.

Basalt has a 3-dimentional molecule and when compared with polymeric fibers, it has higher anti-compressive strength, shear strength, adaptability in any harsh environment, anti-aging, as well as other excellent characteristics. Basalt fiber for cement and concrete is not expensive, it is a competitive alternative product of polypropylene fiber and polyacrylonitrile fiber. Basalt fiber is a typical ceramic fiber, it's easy to disperse when mixed with cement concrete and mortar. Fresh basalt fiber reinforced concrete has good characteristics, such as volume stability, good workability, good stability, excellent thermal resistance, anti-seepage, crack resistance and impact resistance.

2. LITERATURE REVIEW

Arivalagan et al. [1] concluded that the usage of Basalt fibers in low cost composites for civil infrastructure applications gives good mechanical properties like strength and lower cost predicted for basalt fibers. Basalt fiber has used as a cost effectively replace to fiberglass, steel fiber, polypropylene, polyethylene, polyester, aramid and carbon fiber products in many applications.

Krassowska and Lapko [2] concluded that the test results of models of BFRC beams showed a distinct increase in flexural and shear capacity as compared to the beams without fibers.

Jiang et al. [3] concluded that as compared with the plain concrete, concrete reinforced with Basalt fibers have high flexural strength and tensile strength. But the compressive strength of concrete reinforced by Basalt fibers increases slightly at the early age and even decreases at the late age.

Abdulhadi [4] studied the effect of Basalt and Polypropylene Fibers with different volumes and concluded that the compressive strength for C30 grade of concrete from two different type of fiber at different volume fraction shows different degree of reduction. The addition of 0.3%, 0.6%, 0.9% and 1.2% resulted in a decrease of compressive strength relative to plain concrete by 9%, 19%, 1%, and 18% respectively. Similarly, addition of 0.3%, 0.6%, 0.9%, and 1.2% volume of polypropylene resulted in a decrease of strength relative to plain concrete by 8%, 7%, 17% and 24% respectively. It was observed that the incorporation of fibers in the concrete matrix greatly increases splitting tensile strength. The addition of 0.3% and 0.6% volume of basalt fiber increase the splitting tensile strength of concrete by 2.6% and 22.9% respectively; while for 9% and 1.2% volume, the splitting tensile strength of concrete decreased by 11.3% and 19.8% respectively; therefore, the optimum dosage for the splitting tensile strength of basalt fiber is in the vicinity of 0.6%. Also, addition of 0.3%, 0.6%, and 0.9%, volume of polypropylene fiber increase the splitting tensile strength of concrete by 15.1%, 7.8%, and 5.6% respectively; therefore, the optimum dosage for the splitting tensile strength of polypropylene fiber is in the vicinity of 0.3%.

Smriti et al. [5] investigated that for incorporating basalt fiber into composite mix, there is decrease in workability and increase in density as volume fraction of fiber increases. Experimental results showed increase in compressive strength for basalt fiber reinforced composite. Among four different volume fraction of basalt fiber 0.3%,0.5%, 1% and 2%,optimal volume fraction has been found as 0.5% which showed 12% increase in compressive strength. Although mode of failure is nearly same for specimen with and without fiber, but modulus of Elasticity for basalt fiber reinforced composite is higher than composite mix alone. Yet many more experimental investigation needs to be done for showing the effect of basalt fiber on compressive strength enhancement and to get complete ascending and descending branch of stress-strain curve for basalt fiber reinforced composites.

Borhan [6] concluded that the slump of concrete decreases with increasing the volume fraction of basalt fiber and the unit weight is not sensitive to it as the fiber content was low in all mixes. A slight increase in the splitting tensile strength with increase the volume fraction of fiber till 0.3% and then it decreases with 0.5% basalt fiber. The compressive strength increases with increase the fiber content till 0.3% then there is a slight reduction of 12% when 0.5% fiber was used. The modulus of elasticity shows the trend of the strengths results. The addition of basalt fiber to concrete decrease the amount of heat conducted through the thickness.

Jianxun et al. [7] Concluded that for the compression test, the effect of enhancing concrete compressive strength is not prominent by adding presoaked basalt fiber, even might is reduced. But the failure model is modified; the integrity of fiber concrete is kept when the tensile failure occurs. From the tensile test, the effect of enhancing concrete tensile strength is obvious by adding presoaked basalt fiber, and the crack extension slows down, and the toughness and the deformation performance improved. The tensile strength of presoaked basalt fiber concrete is increased with the increase of the dosage and the length of presoaked basalt fiber. When the fiber content is 5kg/m^3 and the fiber length is 20mm, the toughness of presoaked basalt fiber concrete is the best. So we can believe that the presoaked basalt fiber can be regarded as a strengthening material for concrete structures. The presoaked basalt fiber will be a good alternative material among the fiber concretes.

George et al. [8] Studied that, the basalt fiber inclusion enhanced the split tensile and flexural strength of concrete. Through the SEM (Scanning Electron Microscope) analysis, it is confirmed that the rod like structure of basalt fiber observed at the interface of cementitious and aggregate matrix could probably be the reason for the increased split tensile and flexural strength of concrete, as it bridges or connects the weak and strong matrix upon loading. However, the quantitative nature of this benefit is difficult to determine, as it is required to conduct further studies to prove.

Irine [9] concluded that the workability of concrete decreases with the addition of Basalt Fibers. But this difficulty can be overcome by using plasticizers or super-plasticizers. The percentage increase of compressive strength of basalt fiber concrete mix compared with 28 days compressive strength of Plain Concrete is observed as 14%. The percentage increase of split tensile strength of basalt fiber concrete mix compared with 28 days compressive strength of Plain Concrete is observed as 62%. The flexural strength of basalt fiber concrete is also found have a maximum increase of 54% at 4kg/m3 of fiber content. It was observed that, the percentage increase in the strength of basalt reinforced concrete increases with the age of concrete. Also it was found from the failure pattern of the specimens, that the formation of cracks is more in case of concrete without fibers than the basalt fiber reinforced concrete. It shows that the presence of fibers in the concrete acts as the crack arrestors. The ductility characteristics have improved with the addition of basalt fibers. The failure of fiber concrete is gradual as compared to that of brittle failure of plain concrete.

3. EXPERIMENTAL WORK

The main objectives of the experimental program were (a) to investigate the effectiveness of confinement based on the basalt fibers preimpregnated and bonded with concrete (b) to compare the performance (in terms of strength)of different techniques. This investigation was carried out on concrete 24nos.cubes (150mm x150mm x150mm) for finding compressive strength, 20 nos. cylinder (150mm x300mm) for split tensile test and 12 nos beams (700mm x 150mm x 150mm) for flexural test. Each specimen was casted as per IS procedure. After casting the M-30 grade concrete, specimen were demoulded and specimens were kept for a period of 7 and 28 days in the curing tank until the time of test. The detailed mix ratio of M30 grade of concrete is given in Table 1.

Table 1: Quantity of Materials Per Cubic Meter of Concrete

Material	Proportion by Weight	Weight in Kg/m3
Cement	1	492.50
Fine Aggregate	1.39	683.50
Coarse Aggregate	2.26	1115.17
W/C ratio	0.40	197

3.1. Materials Used

3.1.1. Cement. In the present work 53 grade Chettinad cement is used for casting all cubes, cylinders and beams. The cement has uniform colour i.e. grey with a light greenish shade and is free from hard lumps.

3.1.2. Sand. The sand used for the experimental work conform to grading zone I. The sand is sieved through 4.75mm sieve to remove any particle greater than 4.75mm size.

3.1.3. Coarse aggregate. The broken stone is generally used as a coarse aggregate. Locally available coarse aggregate having the maximum size of 20 mm was used in the present work.

3.1.4. Basalt fiber. Basalt fiber is a material made from extremely fine fibers of basalt, which is composed of the minerals plagioclase, pyroxene, and olivine. The fibers used in the study are of 13 µm in diameter and 12 mm in length. Fibers used for this work are 1%,1.5% and 2% by the weight of cement. Some of the properties of basalt fiber are give in Table 2.

Fig. 1: Basalt fiber

Table 2: Physical properties of Basalt fiber.

Sr. No.	Property	Value
1.	Diameter	13µm
2.	Length of fiber	12mm
3.	Appearance	Golden Brown
5.	Tensile strength	4840 MPa
6.	Modulus of elasticity	89000 MPa
7.	Specific gravity	2700 Kg/m3

3.1.5. Water. Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. In the present investigation, tap water is used for both mixing and curing purposes.

3.2. Test procedure

3.2.1. Compression test. Compression strength of concrete with and without basalt was conducted for 7 days, and 28. The load was applied and increased continuously until the resistance of the specimen to the increasing load breaks down. The maximum load applied to the specimen was then recorded. Average of three values was taken as the representatives of the compressive strength of the sample as noted.

The experimental set up for compression test is shown in Fig. 2. The compressive strength of test specimen can be determined by following formula:

$$F_c = \frac{P}{A}$$

Where,

F_c = Compressive strength, MPa.

P = Load at failure, N.

A = Loaded area of cube, mm^2

Fig. 2: Testing of cube

3.2.2. Splitting Tensile Test. The split tensile test were conducted as per IS 5816:1999. The size of cylinder is 300mm length with 150mm diameter. The specimen were kept in water for curing for 7 days, and 28 days and on removal were tested in wet condition by wiping water and grit present on the surface. The test is carried out by placing a cylindrical specimen horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder along the vertical diameter. The maximum load applied to the specimen was then recorded. Average of three values was taken as the representative of batch. Fig. 3 shows the testing of split tensile test.

The split tensile strength of cylinder is calculated by the following formula –

$$F_t = \frac{2P}{\pi LD}$$

Where,

F_t = Tensile strength, MPa

P = Load at failure N

L = Length of cylinder, mm

D = Diameter of cylinder, mm

Fig. 3: Testing of cylinder

3.2.3. Flexural Strength Test. The flexural Strength were tested at 28 day as per IS 516 – 1959 for normal concrete and basalt fiber concrete mixes. Average of three values was taken as the representatives of the Flexural strength. The experimental set up for flexural test is shown in Fig. 4.

The flexural strength was determined by the formula:

$$F_{cr} = \frac{PL}{\text{bd } 2}$$

Where,

F_{cr} = Flexural strength, Mpa.
P = Central load through two point loading system, N.
L= Length of beam, mm.
b = width of beam, mm.
d= depth of beam, mm.

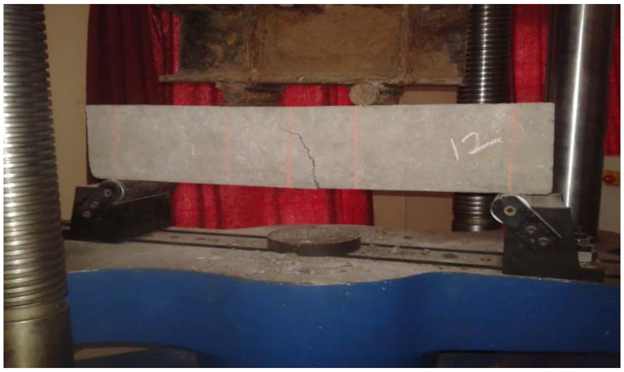

Fig. 4: Testing of beam

4. RESULT AND DISCUSSION

4.1. Compressive Strength

The results of compressive strength are obtained and are presented Table 3. The variation of compressive strength with respect to fiber content is shown in Fig. 5.

Table 3: Compression Strength Values.

Sr. No.	Mix designation	Fiber Content (%)	Compressive strength (MPa)	
			7 Days	28 Days
1.	M0	0.0	27.70	32.59
2.	M1	1.0	31.70	36.89
3.	M2	1.5	29.19	36.44
4.	M3	2.0	28.74	35.85

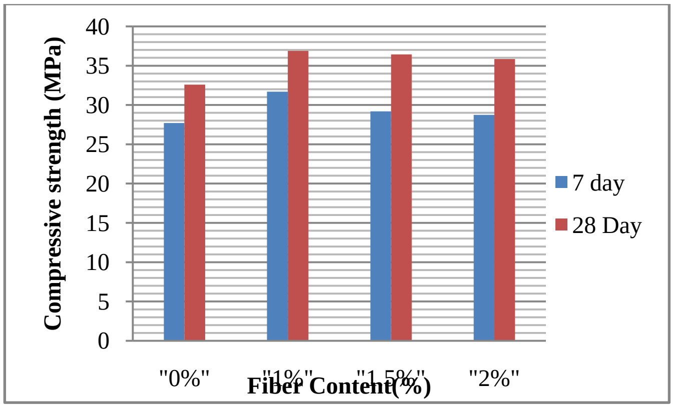

Fig. 5: Compressive strength test results

The Results of compressive strength indicates the optimum fiber content which give maximum strength at 28 days is 1.0 %. The percentage increase in strength at this volume fraction of fibers over normal concrete at 7 and 28 days is 14.47% and 13.19% respectively at 1.0%. After optimum level, there is reduction in compressive strength which indicates air entrapment in the concrete due to incorporation of high fiber volume fraction. The 7 and 28 days variation of compression strength with respect to fiber content is presented in Fig. 5.

4.2. Split tensile Strength

The result of Split tensile strength are obtained and are presented Table 4. The variation of Split tensile strength with respect to fiber volume fraction is shown in Fig. 6.

Table 4: Split tensile Strength Values.

Sr. No.	Mix designation	Fiber content (%)	Split Tensile Strength (N/mm2)	
			7 Days	28 Days
01.	M0	0.0	2.83	2.93
02.	M1	1.0	2.97	3.26
03.	M2	1.5	3.04	3.44
04.	M3	2.0	3.11	3.54

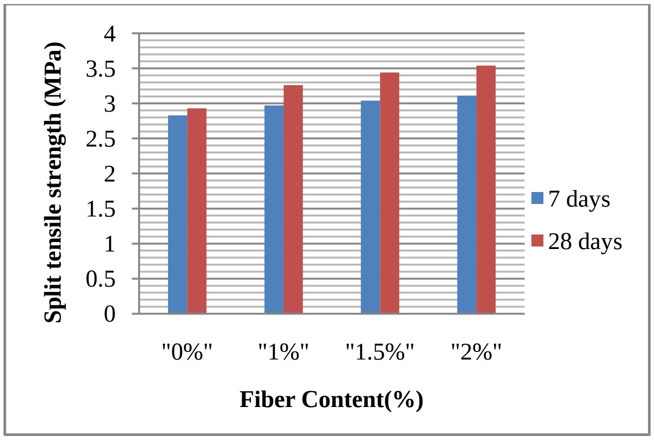

Fig. 6: Split Tensile Strength results.

From Table 4, It indicates the optimum volume fraction of fibers which give maximum strength at 28 days is 2.0 %. the maximum increase in split tensile strength is 9.90% for 7 days and 20.82% for BFRC at 28 days. The split tensile strength increases up to 2.0% 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.

4.3. Flexural strength

Flexural strength is obtained for various fiber volume fraction and results are presented in Table 5. The variation of flexural strength with respect to fiber volume fraction is shown in Fig. 7.

Table 5: Flexural Strength Values

Sr. No	Mix designation	% of Basalt Fiber	Flexural strength in MPa
			28 Days
1.	M0	0.0	4.985
2.	M1	1.0	5.554
3.	M2	1.5	6.319
4.	M3	2.0	6.758

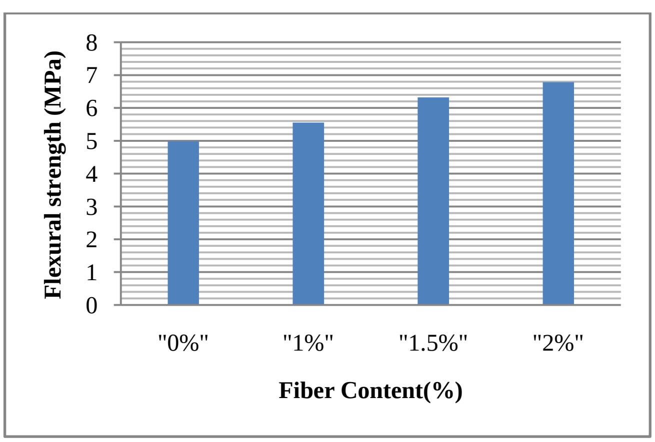

Fig. 7: Flexural Strength results.

From Table 5, it is observed that the flexural strength increases with increase in fiber content up to 2.0%. The maximum value at 28 day is 35.57 %. Thus, there is enhancement in flexural strength of concrete from 11.41% to 35.57% at 28 days. The 28 days variation of flexural strength with respect to fiber content is presented in Fig. 7.

5. CONCLUSION

Among four different contents of basalt fibers, 0%,1%,1.5%, and 2%, The split tensile and flexural strength increases from 0% to 2.0%, but optimum value of compressive strength is obtained for 1.0% and then it is decreases for 1.5% and 2.0% of fiber content.

The Results from experimental studies shows that the optimum percentage of basalt fibers for maximum compressive strength of 36.89 MPa is 1.0 %, which gives 13.19% increase in compressive strength than normal concrete. For maximum Split tensile and flexural strength, optimum fiber content is 2% gives maximum strength of 3.54 MPa and 6.78 MPa which is 20.82% and 35.87% higher than normal concrete.

From the research it was proposed that, the usage of Basalt fibers in low cost composites for civil infrastructure applications gives good mechanical properties like strength and lower cost predicted for basalt fibers. Basalt fiber has used as a cost effectively replace to fiberglass, steel fiber, polypropylene, polyethylene, polyester, aramid and carbon fiber products in many applications.

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