Investigations on Performance of Basalt Fiber Reinforced Concrete

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Abstract - *Fibers are used in concrete to improve its structural integrity. Nowadays, among all basalt fibers, an inert mineral fiber is gaining more importance due to its exceptional properties, which include resistance to corrosion and low thermal conductivity. Blending a certain proportion of basalt fiber into concrete improves the toughness of concrete, which prevents cracking and avoids the brittle behaviors. In this paper, the compressive, tensile, and flexural tests of concrete with different basalt fiber contents were carried out. Then the test phenomena, failure modes, and mechanical properties were compared and analyzed to derive the relationship between the basalt fiber contents and mechanical properties. It can be used to extend the life of important concrete structures such as nuclear power plants, highways, bridges and runways. Basalt fiber in concrete is still an exploratory area due to limited studies. Therefore, a systematic study on basalt Fiber-reinforced concrete was carried out with a percentage volume fraction of Fiber 0%, 1%, 1.5% and 2%.*

Key Words*: *Basalt fiber; concrete; crack resistance; fiber content; mechanical properties; toughness.

1. INTRODUCTION

In this modern age, civil engineering constructions have their own structural and durability requirements, every structure has its own intended purpose and hence to meet this purpose, modification in traditional cement concrete has become mandatory. It has been found that different type of fibers added in specific percentage to concrete improves the mechanical properties, durability and serviceability of the structure. It is now established that one of the important properties of Fiber Reinforced Concrete (FRC) is its superior resistance to cracking and crack propagation [6]. Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers – each of which lend varying properties to the concrete. In addition, the character of fiber reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities. The weak matrix in concrete, when reinforced with fibers, uniformly distributed across its entire mass, gets strengthened enormously, thereby rendering the matrix to behave as a composite material with properties significantly different from conventional concrete. Because of the vast improvements achieved by the addition of fibers to concrete, there are several applications where fibers Reinforced Concrete (FRC) can be intelligently and beneficially used. These fibers have already been used in many large projects involving the construction of industrial floors, pavements, highwayoverlays, etc. in India. These fibers are also used in the production of continuous fibers and are used as a replacement to reinforcing steel. High percentages of steel fibers are used extensively in pavements and in tunneling. Use of basalt fibers are picking up in western countries [7]. Fibers are usually used in concrete to control cracking due to plastic shrinkage and to drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact, abrasion, and shatter–resistance in concrete.

1.1 Basalt Fiber:

Basalt rock is a volcanic rock and can be divided into small particles then formed into continues or chopped fibers. Basalt fiber has a higher working temperature and has a good resistance to chemical attack, impact load, and fire with less poisonous fumes. Some of the potential applications of these basalt composites are: plastic polymer reinforcement, soil strengthening, bridges and highways, industrial floors, heat and sound insulation for residential and industrial buildings, bullet proof vests and retrofitting and rehabilitation of structures. Basalt is fine-grained, extrusive, igneous rock composed of plagioclase, feldspar, pyroxene and magnetite, with or without olivine and containing not more than 53 wt% SiO_2 and less than 5 wt% total alkalis. Many types of basalt contain phenocrysts of olivine, clinopyroxene (augite) and plagioclase feldspar. Basalt is divided into two main types, alkali basalt and tholeiites. They have a similar concentration of SiO_2, but alkali basalts have higher content of NA_2O and K_2O than tholeiites. The production of basalt fibers is similar to the production of glass fibers. Basalt is quarried, crushed and washed and then melted at 1500° C. The molten rock is then extruded through small nozzles to produce continuous filaments of basalt fiber.

Fig -1: Sample Basalt fibers

1.2 Research Objective

The main objective of this experimental work is to investigate the behavior of basalt fiber reinforced concrete compressive strength, tensile strength, flexural strength of concrete using basalt fiber and identify the use of this fibers in regular construction. To study the strength characteristics of basalt fiber concrete are compared with the reference mix (M30 concrete without fiber) and possible use of basalt fiber.

2. LITERATURE REVIEW

A detailed review of literature has been done in order to assess and evaluate the earlier works done on the strength properties of basalt Fiber reinforced concrete.

Basalt is defined by its mineral content and texture, and physical descriptions without mineralogical context may be unreliable in some circumstances. Basalt is usually grey to black in colour, but rapidly weathers to brown or rust-red due to oxidation of its mafic (iron-rich) minerals into rust. Although usually characterized as "dark", basaltic rocks exhibit a wide range of shading due to regional geochemical processes. Due to weathering or high concentrations of plagioclase, some basalt rocks are quite light colored, superficially resembling rhyolite to untrained eyes. Basalt has a fine-grained mineral texture due to the molten rock cooling too quickly for large mineral crystals to grow, although it is often porphyritic, containing the larger crystals formed prior to the extrusion that brought the lava to the surface, embedded in a finer-grained matrix.

Literature based on the physical, mechanical, and chemical properties of concrete. From the detailed literature review, inference is studied.

R. Kamala et al. have studied the literature review on Reuse of Solid Waste from Building Demolition for the Replacement of Natural Aggregates. In this paper, the crushed tile aggregate has been used as partial replacement of convectional coarse aggregate in concrete making of cubes, cylinders, beams. Specimens were casted and tested for compressive strength, split tensile and flexural strength after a curing period of 7, 28, 56 days. But it is observed that the strength decreases from 50% replacement of coarse aggregate. The results show the effectiveness of crushed ceramic waste as partial replacement of conventional coarse aggregate up to 40 percent, without affecting the design strength.

Mohd Monish et al. have investigated on Demolished waste as coarse aggregate in concrete. The effect of partial replacement of coarse aggregate by demolished waste on workability and compressive strength of recycled concrete for the study at 7 and 28 days using experimental study. Three specimens each having 0%, 10%, 20%, and 30% demolished waste as coarse aggregate replacement for mix were cast and tested in order to have a comparative study. From this study, test results showed that the compressive strength of recycled concrete up to 30% replacement of coarse aggregate by demolished waste at the end of 28 days have been found to closer strength to the conventional concrete.

K. Ramadevi et al. have examined on Experimental study on strength properties of concrete with different aspect ratios of basalt Fiber. In this paper, an attempt to predict the impact of basalt Fiber in the design strength of M40 grade concrete. The concrete specimens are cast and tested for three different length of basalt Fiber such as 16 mm, 19 mm and 24 mm are used for the Fiber content of 1%, 2% and 3% to the volume of the concrete. From experimentally study, the variation of mechanical properties with the Fiber length and optimum dosage of Fiber content is found out. Finally result shows that using of higher Fiber length increases in compressive strength, split tensile strength and flexural strength compared to plain concrete control specimen.

Patil Dinanjali et al. have investigated on Performance Evaluation of Basalt Fiber Concrete. The Experimental investigation on basalt concrete has been carried out to evaluate properties of basalt Fiber concrete. The testing carried out on 24 concrete cubes for compressive strength, 12 numbers of cylinders was tested for split tensile test and 4 numbers of beams was teste for various percentage of Fiber like 0, 0.25%, 0.50%, and 0.75%. Testing after 28 days average compressive, flexural, split tensile strength is maximum when 2% Fiber is used. About 20% to 30% increase in strength is observed. From this study, it is concluded that use Basalt Fiber in concrete is an effective technique to enhance performance of concrete.

Kiran Rayanagouda Police Patil et al. have evaluated on Experimental study on strength properties of concrete with partial replacement of cement by Alccofine & replace fine aggregate by m sand. From this study, strength properties of concrete by replacing cement by Alccofine partially. Different percentage of 5%, 10%, 15%. And 20%

of Alccofine by volume of cement. The mechanical properties studied here are compressive strength on concrete cubes at 7 & 28 days of curing and flexural strength on beams at 7 & 28 days of water curing. It is observed from the result that the Alccofine material increases the strength to a large extent at 20% replacement level of cement and there is no reduction in mechanical strength properties by substituting river sand by m sand.

Swar Shah et al. have investigated on Strength and Durability study on Concrete with Alccofine as Cement Replacement. In this study, 20% cement replacement by Alccofine1203 Concrete of M30 Grade is prepared and compressive strength and flexural strength is measured. High Strength Concrete M60, M70, M80 is prepared with 5% cement replacement by Alccofine1203 addition to the M30 grade of concrete and compressive, flexural, split tensile strength is tested. From the experimental Work shows that Replacement of Cement by Alccofine is giving acceptable results. Hence the observed result shows that Alccofine is proper material which can use as partial replacement of cement.

Biseena M Kareem et al. have observed on Effect of Alccofine on Glass Fiber Reinforced Self Compacting Concrete. In this thesis discussed about the effect of Alccofine on the glass Fiber reinforced self-compacting concrete. Various percentages of cement are replaced by Alccofine in the glass Fiber reinforced self-compacting concrete. Evaluated the fresh and strength properties and it is comparing with the normal glass Fiber reinforced selfcompacting concrete. Addition of Alccofine to the glass Fiber reinforced self-compacting concrete enhances its strength properties. Thus, the percentage level of Alccofine is increased more than 10 %, it acts as a filler material only and the strength gradually decreases by increasing the percentage of Alccofine.

Malvika Gautam et al. have investigated on Effect of Alccofine on strength characteristics of Concrete of different grades-A Review. From the experimental study the result of Alccofine material increases the mechanical strength (both in compression and in flexure) to a large level at nearly 10% replacement level of cement have been observed. It is concluded that the 7 days compressive strength when compared between control mix and cement replaced by 10 % Alccofine an increase in strength is observed. Thus, the result shoes that percentage level of Alccofine is increased beyond that level it acts as a filler material and yields good workability to the concrete.

3. EXPERIMENTAL PROGRAM

3.1 Materials Used

In this the various materials used for the study, their properties, test conducted and results are discussed. This section also explains the mix proportions used for the study.

3.2 Cement

The cement used was Portland Slag cement. The following table I is the various tests conducted as per Indian Standard to determine the properties of this cement.

S NO.	PROPERTIES	VALUE
1	Specific gravity	2.91
2	Standard consistency	34%
3	Initial Setting time in minutes	147
4	Final Setting time in minutes	325

Table 1 physical properties of cement

3.3 Fine Aggregate (Sand)

Manufactured sand was used as fine aggregate for the experiments. Various tests were conducted to determine the properties of sand which are shown in table II. Grading is the particle-size distribution of an aggregate as determined by a sieve analysis. The test was done according to IS: 2386 (Part 1) – 1963.

S.NO	PROPERTIES	VALUE
1	Specific gravity	2.54
2	Fineness modulus	2.963
3	Water absorption	1 1%
4	Zone	II

Table 2 Properties of fine aggregate

3.4 Coarse Aggregate

Aggregate is commonly considered inert filler, which accounts for 60 to 80 percent of the volume and 70 to 85 percent of the weight of concrete .Maximum size of aggregate affects the workability and strength of concrete. It also influences the water demand for getting a certain workability and fine aggregate content required for achieving a cohesive mix. In this study the natural coarse aggregates are used, which was bought from the nearby quarry. Aggregates of 20 mm and 12.5 mm size were chosen for the experiment which is clean and free from deleterious materials. The following table III shows the tests conducted in order to determine the properties of this aggregate.

S NO.	PROPERTIES	VALUE
1	Specific gravity (20mm)	2.778
2	Specific gravity (12.5mm)	2.75
3	Fineness modulus(20mm)	2.596
4	Fineness modulus(12.5mm)	2.273
5	Water absorption(20mm)	0.5%
6	Water absorption(12.5mm)	0.9%

Table 3 Properties of coarse aggregate

3.5 Super plasticizer

In modern concrete practice, it is essentially impossible to make high performance concrete at adequate workability in the field without the use of super plasticizers. The super plasticizer used in the study was Conplast 8233.

3.6 Basalt Fiber

The fibers used were chopped basalt fibers which are uniformly and randomly distributed in the concrete matrix. Three different fiber content were chosen 0%, 1%, 1.5% & 2% each mix.

3.7 Concrete mix proportions

The mixture proportioning was done according the Indian Standard Recommended Method IS 10262-2009.The target mean strength was 30 MPa for the control mixture, the total cement content was 420 kg/m3 , fine aggregate is taken 828 kg/m3 and coarse aggregate is taken 1123kg/m3, the water to cement ratio was kept as 0.45, the Super plasticizer content was taken as 0.3% for all mixtures. The total mixing time was 5 minutes, the samples were then casted and left for 24 hrs before demoulding .They were then placed in the curing tank until the day of testing Cement, sand, Basalt fiber and fine and coarse aggregate were properly mixed together in accordance with IS code before water was added and was properly mixed together to achieve homogenous material. Water absorption capacity and moisture content were taken into consideration and appropriately subtracted from the water/cement ratio used for mixing.150 × 150 × 150mm3 cubes, 500mm × 100 × 100mm3 Beam and 150 mm diameter and 300 mm height Cylinder moulds were used for casting. The concrete specimens were cured in the tank for 3, 7, 28 days.

4. RESULTS AND DISCUSSIONS

All the tests have been performed in standard procedures and the results and load values obtained were tabulated and calculated in following sections.

4.1 Workability

Slump test was carried out on each mix to ascertain workability of BFRC as well as control mixtures. The results of slump tests for M-30 grade concrete with and without Basalt Fibers are shown in table.

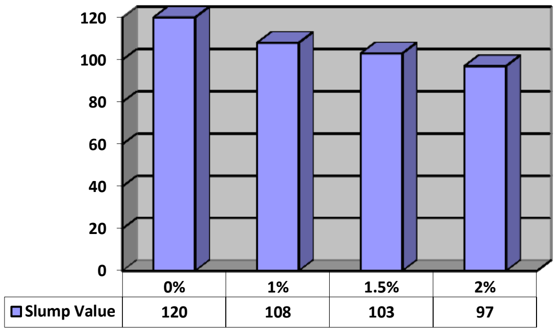

Table -4 Slump values

4.2 Compressive Strength

Compressive strength tests were conducted on cured cube specimen at 7 days and 28 days age using a compression testing machine of 200 kN capacity. The cubes were fitted at center in compression testing machine and fixed to keep the cube in position. The load was then slowly applied to the tested cube until failure.

Sl.no	Mix (days)	Fiber Content	Cube Compressive strength (N/mm^2)
1	7	0%	25.1
		1%	25.67
		1.5%	27.75
		2%	28.89
2	28	0%	35.4
		1%	36.5
		1.5%	38.4
		2%	40.2

Table-5 Compressive Strength values

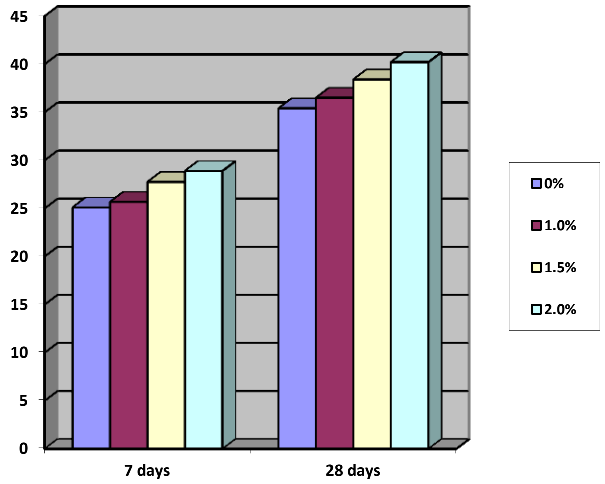

Chart-1 Compressive Strength

4.3 Split Tensile Strength

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.

Sl.no	Mix (days)	Fiber Content	Cylinder Split Tensile strength (N/mm^2)
1	7	0%	1.65
		1%	2.3
		1.5%	2.64
		2%	2.87
2	28	0%	2.25
		1%	3.02
		1.5%	3.33
		2%	3.64

Table -6 Split Tensile Strength values

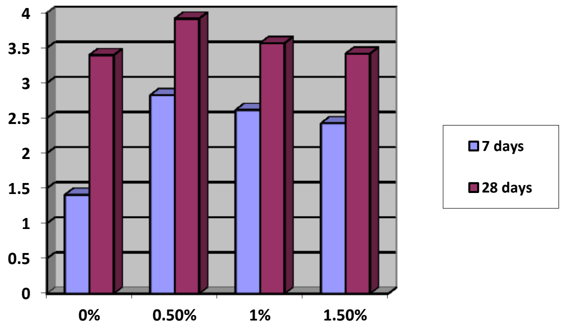

Chart-2 Split Tensile Strength

4.4 Flexural Strength

The Flexural tests were conducted as per IS 516:1959. The size of beam is 100mm*100mm*500mm. The specimen were kept in water for curing for 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 Beam specimen horizontally such that the load shall be divided equally between the two loading rollers, and all rollers shall be mounted in such a manner that the load is applied axially and without subjecting the specimen to any torsional stresses or restraints.

Sl.no	Mix (days)	Fiber Content	Beam Flexural strength (N/mm^2)
1	7	0%	3.3
		1%	4.2
		1.5%	4.8
		2%	6.2
2	28	0%	5.2
		1%	5.8
		1.5%	6.6
		2%	8

Table -7 Flexure Strength values

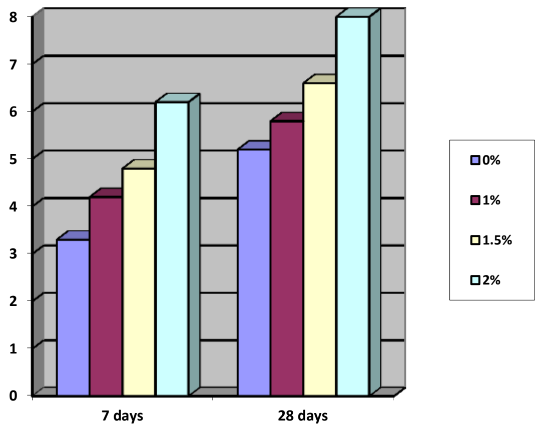

Chart -3 Flexural Strength

5. SUMMARY AND CONCLUSIONS

The primary aim of this research is to determine the effectiveness of using commercially available basalt fibers as an additive in cementitious materials to enhance the mechanical properties of traditional concrete and increase the flexibility of concrete structures to avoid cracking and spalling.

As a consequence of the experiments and their findings, the following conclusions were drawn.

The slump test results obtained from the concrete mixes prepared with the different ratios of fiber content are given in Table4.1. Data shows that the slump values gradually decrease with an increasing amount of Basalt Fibers. The control mixes have the slump values of 12 cm. These reductions in the slump test results are attributed to the network structures which are formed due to the BFs scattered in the concrete. This structure causes to restrain the mixture from segregation and flow. Owing to the high fiber content and large fiber surface area, the BFs are able to absorb more cement paste wrapping around, which increases the viscosity of mixture and subsequently leads to the loss of slump (Chen and Liu, 2005). The higher the BF content is, the more viscous the concrete becomes. Therefore, high BF utilization can be proposed for the conventional concretes of plastic or stiff consistency. Increasing the amount of super-plasticizer to improve the workability of high BF included concrete may lead the problems of bleeding and segregation.

Comparison of results of compressive strength using cube specimen of M30 grade concrete. It is observed that for addition of 2kg/m^3 fiber gives more compressive strength than other volume fraction.

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 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 2kg/m^3 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 the 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.

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