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A Study on Strength Characteristics of Concrete by Addition of Basalt Fiber

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ABSTRACT- Concrete is one of the oldest and most widely used building materials in the world, mostly because it is inexpensive and readily available. In all areas of contemporary construction, concrete has become a key component of structures. It is challenging to name another building material that is as versatile as concrete. When strength, durability, impermeability, fire resistance, and absorption resistance are needed, concrete is the ideal material to use. This study's main goal is to compare plain M30 grade concrete to basalt fiber concrete in terms of compressive, flexural, and splitting tensile strength. Basalt fiber is a substance created from the incredibly tiny basalt fibers that naturally occur in volcanic rocks that are the result of frozen lava. In the aerospace and automobile industries, it is utilized as a fire-resistant textile. Fibers are typically added to concrete to strengthen its structural stability. Due to its remarkable qualities, such as resistance to corrosion and low thermal conductivity, basalt fiber is currently among the fibers that is gaining more prominence. Additionally, it increases the concrete's toughness, flexural strength, and tensile strength. Important concrete constructions like nuclear power stations, roads, and bridges can employ it to prolong their lifespan. The variable factors taken into account in this study were M30 grade concrete cubes, cylinders, and beams, which were cast and cured in portable water for 28 days. The cubes' dimensions were 150 x 150 x 150 mm, the cylinders' dimensions were 150 mm (dia) x 300 mm (depth), and the beams' dimensions were 500 x 100 x 100 mm. Then, at 7, 14, and 28 days, the specimens were examined for split tensile strength, flexural strength, and compression strength using ordinary concrete with and without basalt fiber.

KEYWORDS- Split tensile strength, Flexural strength, Compressive strength, Basalt fiber, and Concrete.

I. INTRODUCTION

Concrete is often a material with higher compressive strength than tensile strength [1]. It is typically reinforced with some materials that are strong in tension, like steel, due to its reduced tensile stress [2]. Concrete's elastic behavior is essentially stable at low stress levels but begins to change as matrix cracking takes hold at higher stress levels [3]. Concrete shrinks as it ages because of its low thermal expansion coefficient [4]. All concrete constructions have some degree of cracking because of shrinkage and strain [5]. When concrete is subjected to long-term stresses, it is prone to creep [6]. Various tests are conducted for the applications to guarantee the concrete's qualities match the criteria [7]. Different combinations of concrete materials, measured in psi or Mpa, produce concrete with varying strengths [8]. Concrete with varying strengths is utilized for various construction projects [9]. Very low-strength concrete may be utilized if the concrete must be lightweight [10]. By adding air, foam, or lightweight aggregates, lightweight concrete can be produced; however, doing so will weaken the concrete's strength. For regular projects, concrete between 3000- and 4000-psi is frequently employed [11]. Although it costs more, commercially speaking, the 5000-psi concrete choice is one that is more resilient [12]. Larger civil projects frequently employ 5000-psi concrete. Concrete with a strength of more than 5000 psi was frequently employed for particular building components. For instance, to maintain small column diameters in high-rise concrete structures, the bottom level columns may be made of concrete with a strength of 12,000 psi or higher.

Although high strength concrete is thought to be a relatively new material, it has been developing throughout time. The United States regarded concrete with a compressive strength of 34 MPa as having good strength in the 1950s. Concrete having compressive strengths between 41 MPa and 52 MPa was used commercially in the 1960s. Early in the 1970s, 62 MPa concrete was produced. However, given the current state of affairs, extremely strong concrete has only recently entered the construction of high-rise structures and long span bridges. IS 456-2000 has taken into consideration compressive strengths more than 110 mpa for usage in cast-in-place structures and pre-stressed concrete members. But the concrete that has just reacted might be the strongest, with a compressive strength of around 250 mpa. Pozzolanic materials provide complete support for it. The first difference between high-strength and nominal-strength concrete relates to the maximum resistance provided by the concrete sample's compressive strength for the application of any form of load. Although there is no precise distinction between high-strength and normal-strength concrete, the Yankee Concrete Institute classified high-strength concrete as having a compressive strength more than 42 MPa.

II. MATERIALS

A. *Cement*

Ordinary as a fundamental component of concrete, mortar, stucco, and the majority of nonspecialty grout, Portland cement is the type of cement that is most frequently used on a global scale. It typically comes from limestone and evolved from other varieties of hydraulic lime in England in the middle of the 19th century. It is a fine powder that is created when materials are heated to create clinker. We will mix in modest amounts of the remaining ingredients after grinding the clinker. There are numerous varieties of cements on the market. Comparing other cement grades, the 53 Grade OPC Cement consistently offers greater strength than others.

Figure 1: Cement

- Specific gravity (Le- Chatelier flask) (IS: 1727-1967)
- Slump test (Slump cone) (IS: 1199 – 1959)
- Sieve analysis (IS: 2306 (Part-1)-1963)
- Test of compressive strength of concrete. (IS: 516-1959)
- Test of Flexural strength test of concrete (IS: 516-1959)
- Split tensile strength test (IS: 5816-1999).

Plain Portland cement (OPC), which was acquired from Deccan cement, was the cement used in this investigation. Ordinary Portland Cement (OPC) is the most important form of cement and is the cement that is most frequently utilized in the construction business in Ongole. On the 28th day, OPCs were divided into three grades—33 grades, 43 grades, and 53 grades—when examined in accordance with IS 4031-1988. Cement of grades 33, 43, and 53 is defined as having a 28-day strength of 33N/mm2, 43N/mm2, or more, respectively.

Table 1: Properties of cement

SL.NO	Properties	Test results	IS: 169-1989
1.	Normal consistency	0.45	
2.	Initial setting time	29min	Minimum of 30min
3.	Final setting time	598min	Maximum of 600min
4.	Specific gravity	3.18	

For this experiment, Portland cement grade 53 that complies with IS: 8112-1989 and IS 12269-1987 is employed. In the table below, a number of cement's qualities are displayed. Observe a range of benchmark tests in accordance with IS advice.

B. *Fine Aggregate*

Clean river sand was employed as the fine aggregate in this inquiry, and the following tests were performed in sand in accordance with IS: 2386-1968 (iii). Analysis of Fine Coefficient and Specific Gravity. Fine aggregates (i.e., 10 mm) and fine sand are frequently the same components used in combinations for traditional concrete. Agglomerates have passed gradient tests, which demonstrate that they adhere to specifications. Fine aggregates are defined as those with fine adjustment sizes less than 4.75 mm.

Figure 2: Natural Sand

The long-term sedimentation tests should be challenging to validate in the presence of organic compounds and sludge in the fine aggregates, and the particles should be free of clay or other inorganic elements. It is kept in a dry, open location away from moisture. It complies with the Zone II-specific IS 383 1970 standard. The table below displays the fine aggregate's physical characteristics.

Table2: Properties of fine aggregate

S. No	Description Test	Result
1	Sand zone	Zone- II
2	Specific gravity	2.63
3	Free Moisture	0.01
4	Fineness modulus	3.19

C. *Coarse Aggregate*

In this survey, we used a shredded granite stone of a size that is less than 20 mm in size and various tests beneath it.

- Specific gravity (IS: 2386-1968, Part 3)
- Sieve Analysis and Precision Coefficient (IS: 2386-1968, Part 3)

When the total size is greater than 4.75 mm, an aggregate is deemed coarse. It's on the original rock, of course. In addition to being angular or sheet-like, rough aggregates can also be round, irregular or partially rounded. The amount of dust in them must be minimal, and they must be devoid of organic contaminants. The question of whether colloidal or spherical particles will produce better concrete is highly debatable. If you require all round accounts for financial reasons, you must first break them before using them. The next two points, however, are where the angular aggregate exceeds the round aggregate.

- Interlocking effect with concrete is excellent.

- The total surface area of coarse tissue aggregates is a smoother rounded aggregate for a given volume.

Figure 3: Aggregates

For the experiment, locally accessible dried angle coarse aggregates with a maximum size of 20 mm and a minimum size of 10 mm were employed.

Table 3: Properties of coarse aggregates

S. No	Description	Test Results
1	Nominal size used	20mm
2	Specific gravity	2.77
3	Fineness modulus	7.22
4	Water absorption	0.15%

D. Water

Due to its active participation in chemical reactions with cement, water is a crucial component of concrete. This is because the cement gel has been strengthened, and the concrete is easy to work with. You should thoroughly examine the water's quantity and quality. Concrete is hydrated with portable water.

Table 4: Properties of water

S. No	Properties	Value
1	PH	7.25
2	Taste	Agreeable
3	Appearance	Clear
4	Turbidity(NT units)	3.85

Figure 4: Water

E. Basaltfibers

Basalt fiber is referred to as a green industrial material and is also referred to as the "nonpolluting green material of the twenty-first century." Basalt is a naturally occurring substance that is present in volcanic rocks that were formed from frozen lava. Its melting range is between 15000C and 17000C. Basalt fibers are inert and entirely natural. They have been examined and found to be both nontoxic and no carcinogenic. Because basalt fibers are formed of natural resources and are produced without the use of solvents, colors, or other dangerous elements, basalt fiber can be categorized as a sustainable material. The basalt fiber has a specific gravity of 2.7.

Figure 5: Basalt fiber

Table 5: chemical composition of Basalt fiber

Chemical components	Basalt weight %
SiO_2 (silica)	57.5
Al_2O_3 (alumina)	16.9
Fe_2O_3 (ferric oxide)	9.5
CaO	7.8
MgO	3.7
Na_2O	2.5

III. PREPARATION OF CONCRETE SPECIMEN

A. Process of Manufacturing of Concrete

Concrete production quality demands precise attention at every stage. The final concrete will be of poor quality if diligent care is not taken and good guidelines are not followed. Good concrete will be produced from the same material provided extreme care is taken to control at every stage. Therefore, in order to produce quality concrete, we must understand the good guidelines that should be followed at each stage of the manufacturing process. The many steps in the production of concrete are as follows:

B. Batching

Batching of concrete refers to the procedure of metering ingredients or supplies to make concrete mix. Volume batching and weight batching are two techniques for batching. To obtain a high-quality concrete mix, batching must be done correctly. The most accurate form of batching is the weight batching method. Always use a weight batching system for essential concrete. In this procedure, materials are weighed and then measured according to their weight on a weighing balance. Weighing is used to measure out the cement, fine aggregate, coarse aggregate, and water.

Figure 6: Materials

Figure 8: Casting

C. Mixing

Mixing of concrete is simply defined as the complete blending of the materials which are required for the production of a homogenous concrete. It is essential that the mix ingredients are properly mixed so as to produce fresh concrete in which the surface of all aggregate particles is coated with cement paste and which is homogenous and therefore possessing uniform properties. Mixing should ensure that the mass becomes homogenous, uniform in colour and consistency.

Figure 7: Mixing

There is a risk of corrosion because cracks play the main

D. Casting

Before making the mix, test molds are kept ready. All contact surfaces of the molds have been cleaned and lubricated. Before casting, they were firmly tightened to the proper size. Care was taken to ensure that there are no holes where slurry may potentially leak out. A trowel is used to level the top surfaces of concrete. On the top of the surface of cubes, cylinders, and beams are written the casting number and date. The specimen was then left in the mold for 24 hours in an ambient environment.

E. Curing

Curing is the process of keeping freshly cast concrete at an acceptable temperature and moisture content for a predetermined amount of time after placement. The procedure accomplishes two main goals. It stops or replaces moisture loss from the concrete and keeps the temperature just right for hydration to take place for a set amount of time. We cure concrete to increase structural integrity and decrease cracks, which maximizes its strength.

Figure 9: Curing

IV. EXPERIMENTAL DETAILS

The various mix proportions used in the trials and the outcomes of the studies with regard to their workability, compressive strength, split tensile strength, flexural strength, and durability test are covered in this chapter.

A. Workability

Fresh concrete's ability to fully compress without bleeding or segregation in the final product is measured by the quantity of practical internal work required. One of the physical characteristics of concrete that influences strength and durability as well as labor costs and final product look is workability. When concrete is put and compacted uniformly, that is, without bleeding or segregation, it is considered to be workable. Unworkable concrete requires more work or effort to compact in situ, and completed concrete may also have honeycombs or pockets evident.

B. Differenttest Methods For Workability Measurement

The workability of concrete can be assessed using one of

the three methods below, depending on the water cement ratio in the mixture.
1. Slump Test
2. Compaction Factor Test
3. Vee-bee consist meter test

In this study, the workability of concrete was evaluated using the slump-cone test and compaction factor tests. Below are the test procedures:

C. SLUMP TEST

Slump the mold on a flat, smooth, and absorbent-free surface. Add the necessary amount of water after fully combining the dry ingredients for the concrete to get a consistent color. Fill the mold with the mixed concrete until it is about one-fourth of the way up. Using a tamping rod, compact the concrete uniformly throughout the area 25 times. Place the mixed concrete in the mold until it is about halfway up, then compact it once more. In a similar manner, place the concrete up to its third height, then to its top. With the use of a tamping rod, compact each layer uniformly 25 times. The tamping rod should pierce the second and subsequent layers for the second and subsequent layers. With a trowel or tamping rod, remove the mold's top surface to fill it all the way to the top. As soon as possible, remove the mold, making sure it moves in a vertical orientation. Measure the concrete's subsidence in millimeters, which is the required slump of the concrete, once the settlement of the concrete has stopped.

Figure 10: Slump testing

D. Compaction Factor Test

The mold's inside surface should be cleaned and dried. Place the concrete in top hopper A with a hand scoop. To make it easier for the concrete to fall into lower hopper B, open the hopper's trap door. With the use of a steel rod, the concrete that is adhering to the hopper A's walls should be forced downward. Let the concrete flow into cylinder C by opening the hopper B's trap door. Utilizing a trowel, remove the extra concrete from the cylinder's top. Clean and wipe the cylinder's exterior surface Weigh the concrete that is just slightly compacted around the cylinder. Fresh concrete should be poured into the cylinder in layers no thicker than 5 cm, and each layer should be compacted until the cylinder is completely filled. Clean and scrub the cylinder's exterior before weighing it with fully compacted concrete. Then, use the formula below to calculate the compaction factor's value.

Compaction factor = weight of partially compacted concrete/weight of fully compacted concrete

E. Compression Strength

Since compression testing is the most common test performed on a hardness test, and partially smooth, most of the desired properties of concrete are partially correlated with compressive strength. The compressive strength test samples were 150 mm x 150 mm x 150 mm. The samples were tested at 2000 kN after 28 days of treatment Cubic or cylinder specimens must be used for compression tests. Although not prevalent in our country, the publication is also used. In some cases, a portion of the package that was tested at flex is used to assess the concrete's compression strength. The rectangular shape of the beam section and the fact that the end of the beam is still clean after the bending failure allow you to utilize this portion of the beam to calculate the compression strength. The cylindrical sample has a length that is double its diameter.

The above-described cured cube specimen is taken out of the curing tank, examined in accordance with industry standards, and then left to dry in the shade. A 2000 KN capacity compression tester is used to test the cubes, and the findings are tabulated.

- Compression Testing Machine

Figure 11: Testing

F. Split Tensile Strength

This method of indirect tensile testing is the simplest to use and yields more consistent results than other tensile tests. The rupture coefficient, which measures the true strength of the concrete, has no bearing on the strength measured in the spilt tensile test. A figure that is between 5 and 12 percent higher than direct tensile strength is provided by split strength.

- *Test placement and testing details are as follows*

The standard mark is the compression tester used to figure out the tensile strength of the cylinder. The machine has a control valve that allows the loading speed to be altered. At the usual loading rate, the machine was calibrated. It maintains testing readiness on all sides while cleaning the pattern and checking the oil level. Using a 2000 KN test device, the diameter of a cylinder with a 150 mm inside diameter and one with a 300 mm outside diameter must be evaluated for separation tension. The elements in the vertical diameter of the cylinder are exposed to both vertical pressure and horizontal pressure (2p/LD) when the load is applied along the conduction rod. The cylinder is seen to be split into two pieces.

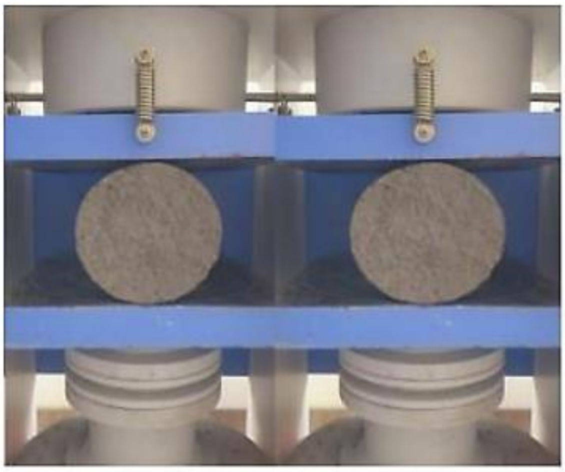

Figure 12: Testing of Split Tensile Test

Split-tensile strength= 2P /π LD

G. *Flexural strength*

As is well knowledge, concrete is weak in tension and moderately strong in compression. A small amount of assurance is given to the tensile strength of reinforced concrete elements by the provision of steel reinforcing bars that can withstand all tensile stresses. Tensile forces, however, can develop in concrete for a variety of reasons, including drying shrinkage, reinforcing steel corrosion, temperature gradients, and many more. Therefore, it is crucial to understand the tensile strength of concrete. Direct measurement of concrete's tensile strength is challenging. No test specimens or testing tools have been created to guarantee a consistent distribution of concrete applied with a "pull" technique. Beam tests have been shown to be accurate in assessing the bending strength qualities of concrete in beams despite numerous investigations, including direct measurement of tensile strength. Holding the central point while carrying the other three points is the load system used to gauge emotional stress. The load of the center point below the point of loading where the bending moment reaches its greatest will result in the highest fiber stress. A fracture may develop for a symmetrical two-point load in any location where the bending moment is insufficient to support the intermediate third stressIt is reasonable to assume that the rupture coefficients for the two point loads will be smaller than those for the center point loads. The sample is typically 100 mm x 100 mm x 500 mm in size. The sample is set up in the machine so that the casting face may receive the load. The load was delivered at an increasing rate without result after lining up the sample axis with the load device axis, and the load applied to the failure was recorded. The specimen's flexural strength is expressed in terms of the fcr rupture modulus.

fcr= PL/BD2

Figure 13: Flexural Testing Set up

V. RESULTS AND DISCUSSIONS

A. *Slump Cone Test*

The test was carried out on freshly prepared concrete that had not yet undergone molding. There are four different concrete mixtures created at various times. Workability The table below displays the slump cone test results for concrete of grade M30.
Test results from slump cone test for workability in mm

Table 6: Slump test Result

S. No	Basalt fiber %	Workability (mm)
		Slump value
1	0	100
2	0.1	92
3	0.2	85
4	0.3	74
5	0.4	65

As the mix proportion increases, the workability determined by the slump cone test increases. Concrete's range of workability is expanding as previously mentioned, but it remains in the medium range generally.

B. *Compressive Strength Test*

Following the workability tests, 45 cubes measuring 150 x 150 x 150 mm were cast and tested for 7 days, 14 days, and 28 days. The outcomes are listed below.:
Compressive strength results of M30 grade of concrete for 7, 24 and 28 days

Table: 7 Compressive Strength Vs Basalt fiber

S. No	Basalt fiber %	Compressive strength of M30 grade in N/mm²		
		7 days	14 days	28 days
1	0	25.02	31.2	35.24
2	0.1	26.24	32.4	37.2
3	0.2	27.43	32.92	37.9
4	0.3	27.92	33.08	38.42
5	0.4	27.78	32.89	37.78

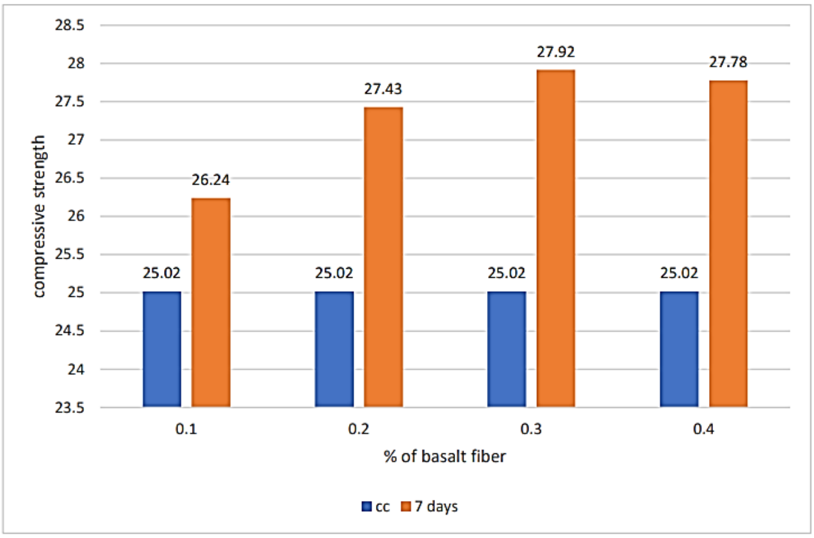

Figure 14: Comparison of Compressive strength of M30 at 7 days

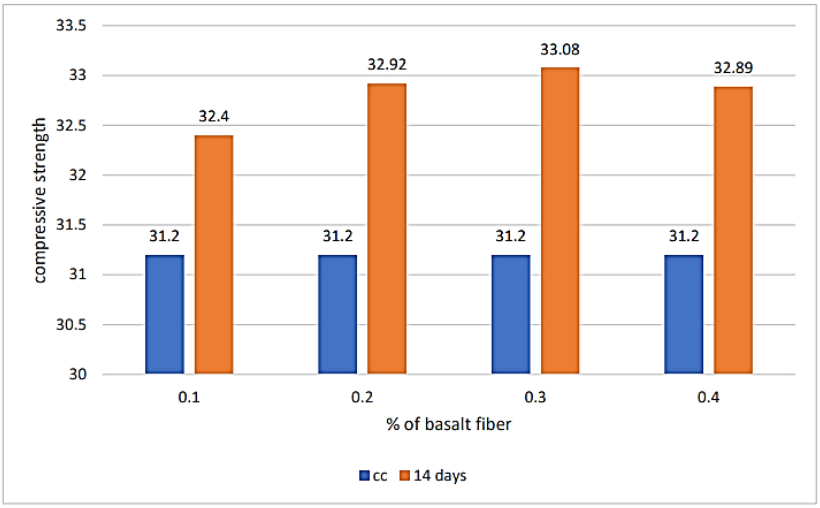

Figure 15: Comparison of Compressive strength of M30 at 14 days

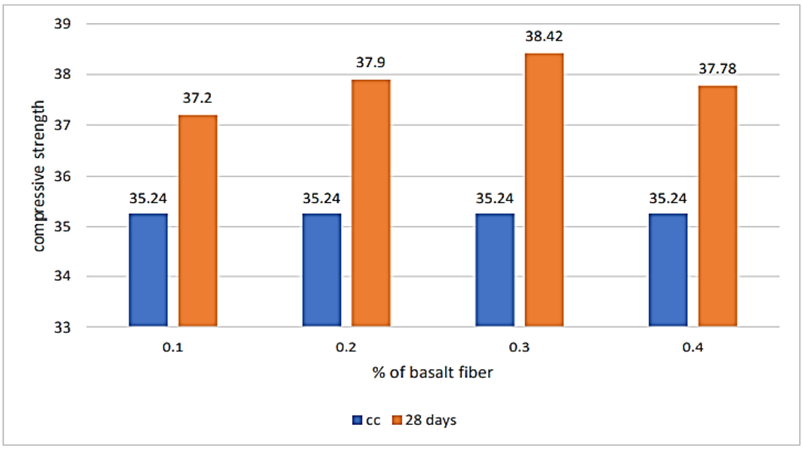

Figure 16: Comparison of Compressive strength of M30 at 28 days

Table 8: Properties of Fine Aggregate

S.no	Property	Test Result	IS Code number
1.	Specific gravity(G)	2.704	IS 2383 -1986
2.	Fineness Modulus	7.55	IS 2383 (Part-1)-1963

C. *Slump Test Values*

Following the workability tests, a total of 30 cylinders with dimensions of 300 x 150 mm were cast and tested for 7 days, 14 days, and 28 days. The outcomes are listed below

Table 9: Split tensile strength results for M30 grade of concrete

S. No	Basalt fiber %	Split Tensile Strength of M30 grade in N/mm²		
		7 days	14 days	28 days
1	0	2.54	3.19	4.2
2	0.1	2.72	3.34	4.31
3	0.2	2.94	3.91	4.45
4	0.3	3.052	4.02	4,71
5	0.4	3.013	3.92	4.68

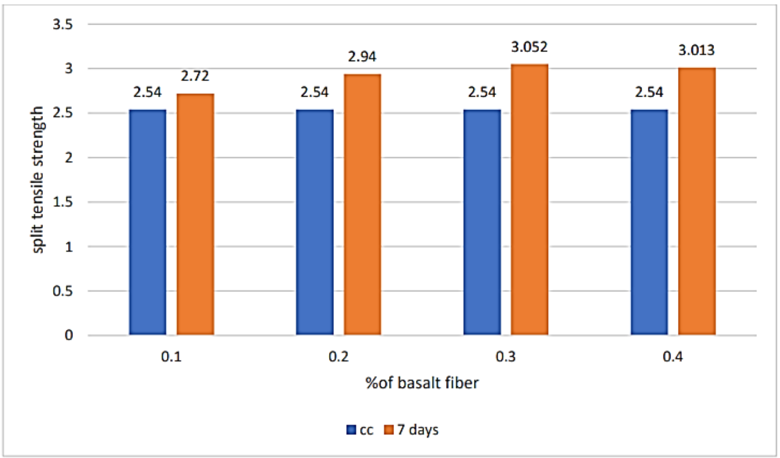

Figure 17: Comparison of Split tensile strength of M30 at 7days

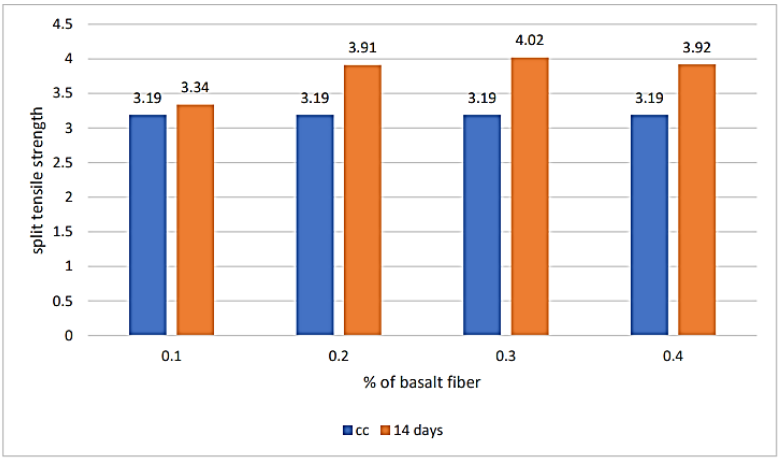

Figure 18: Comparison of Split tensile strength of M30 at 14days

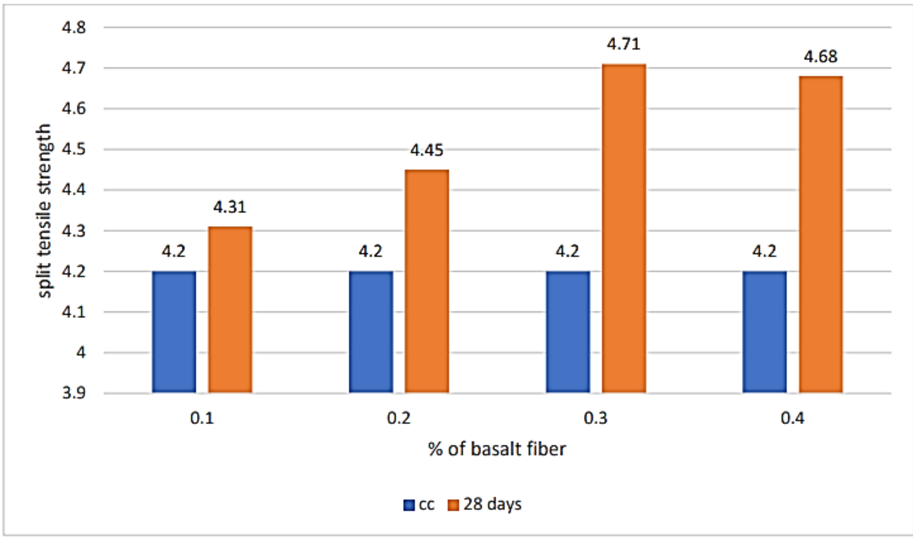

Figure 19: Comparison of Split tensile strength of M30 at 28days

The results show that the strength, or tensile strength, is higher than that of ordinary concrete at all curing ages of 7 days, 14 days, and 28 days. The strength of the concrete is improved by the addition of basalt fiber in varying amounts.

D. Flexural Strength Values

Following the workability tests, 15 beams with a total dimension of 500 x 100 mm were cast and tested for 7 days, 14 days, and 28 days. The outcomes are listed below.

Table 10: Flexural strength results for M30 grade of concrete

S. No	Basalt fiber %	Flexural Strength of M30 grade in N/mm²		
		7 days	14 days	28 days
1	0	5.64	6.94	8.36
2	0.1	6.12	7.281	9.34
3	0.2	6.541	7.892	10.3242
4	0.3	6.9125	8.12	11.42
5	0.4	6.8012	8.052	10.95

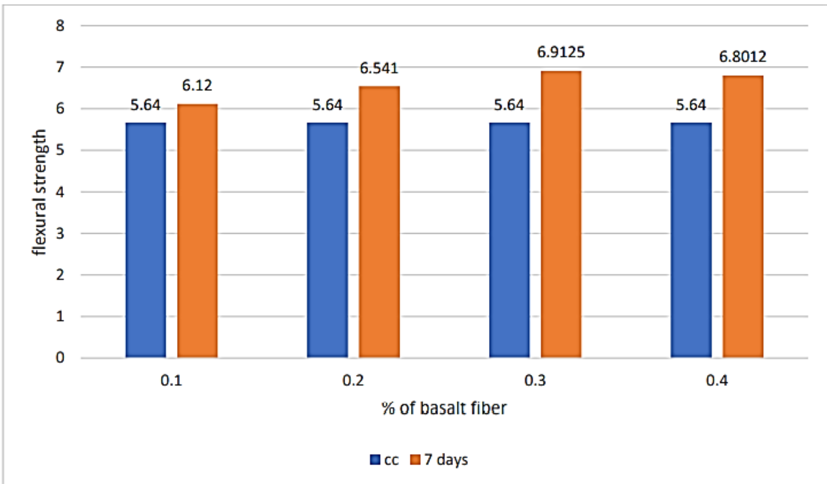

Figure 20: Comparison of flexural strength of M30 concrete at 7days

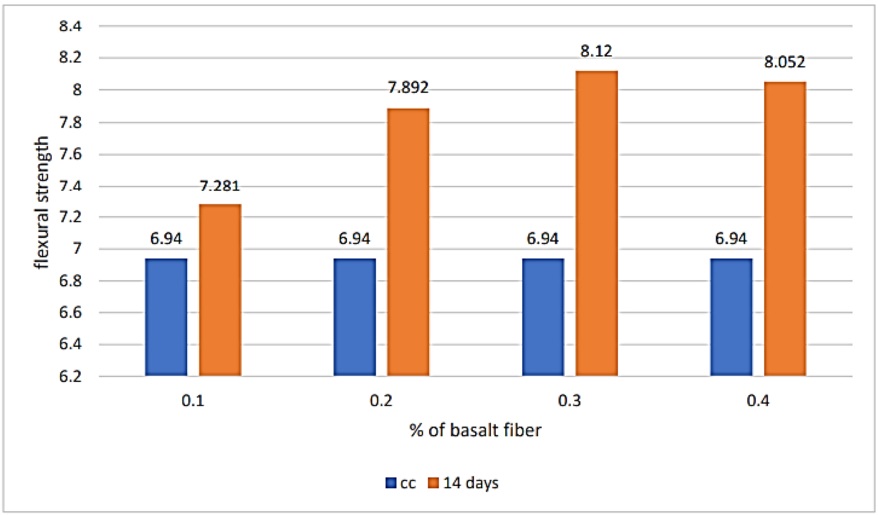

Figure 21: Comparison of flexural strength of M30 concrete at 14days

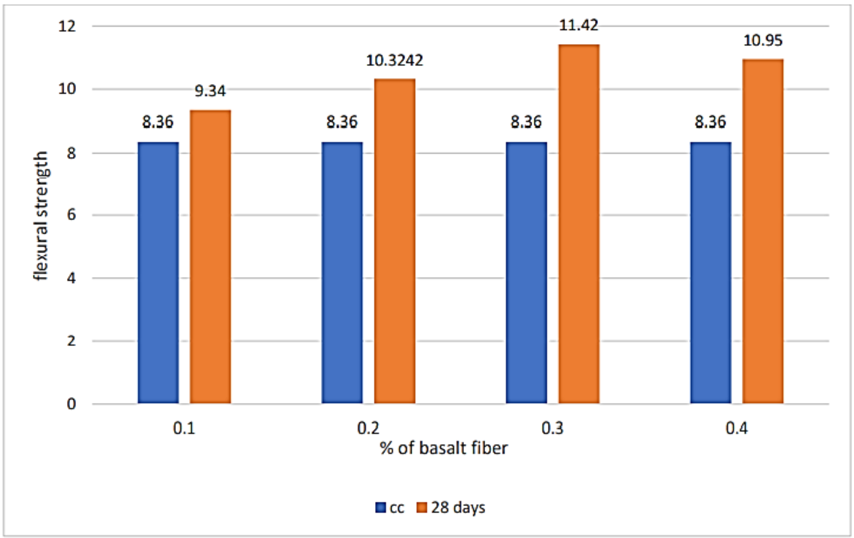

Figure 22: Comparison of flexural strength of M30 concrete at 28days

The results show that the strength, or flexural strength, is significantly higher than that of ordinary concrete at all curing ages of 7 days, 14 days, and 28 days. The strength of the concrete is improved by the addition of basalt fiber in varying amounts.

VI. CONCLUSION

Contrary to normal concrete, basalt fiber concrete has higher compressive, flexural, and tensile strengths.

- As the percentage of the basalt fiber in concrete increases workability of concrete decreases.
- Conventional concrete made with basalt fiber exhibits positive results from a strength perspective.
- It was discovered from the specimens' failure pattern that basalt fiber concrete cracked more frequently than concrete without fibers.
- Concrete's mechanical qualities are improved by basalt fiber.
- Basalt fibre was found to be amorphous in nature.
- It is possible to use basalt fiber in the field of reinforced cement and concrete.
- The addition of basalt fiber had a greater compressive and flexural strength at early stages.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

[1] M.E. Arslan, Effects of basalt and glass chopped fibres addition on fracture energy and mechanical properties of ordinary concrete: CMOD measurement. Constr. Build. Mater. 114, 383–391 (2016)

[2] C. Jiang, K. Fan, F. Wu, D. Chen, Experimental study on the mechanical properties and microstructure of chopped basalt fibre reinforced concrete. Mater. Des. 58, 187–193 (2014)

[3] J. Branston, S. Das, S.Y. Kenno, C. Taylor, Mechanical behaviour of basalt fibre reinforced concrete. Constr. Build. Mater. 124, 878–886 (2016)

[4] S. Mindness, in Proceedings of the International Conference Sustainable Construction Materials and Technologies. Thirty years of fibre reinforced concrete research at the University of British Columbia (Columbia, 2007), pp. 259–268

[5] S.K. Singh, S.K. Kirthika, S.R. Karade, U. Verma. Basalt fibre: a potential construction material. Emerging Building

Materials and Construction Technologies conducted by: BMTPC, New Delhi on March 21 and 22 (2016), pp. 185–194

[6] V. Dhand, G. Mittal, K.Y. Rhee, S.J. Park, D. Hui, A short review on basalt fibre reinforced polymer composites. Compos. B 73, 166–180 (2015)

[7] T. Ayub, N. Shafiq, M. Nuruddin, Effect of chopped basalt fibres on the mechanical properties and microstructure of high performance fibre reinforced concrete. Adv. Mater. Sci. Eng. 2014, 1–15 (2014)

[8] S.K. Kirthika, S.K. Singh, M. Surya, Durability studies on basalt fiber reinforced concrete. Indian Concr. J. (ICJ) 92(4), 45–55 (2018)

[9] V. B. Brik, Advanced concept concrete using basalt fibre composite reinforcement. Tech Res Report submitted to NCHRPIDEA, Project 25 (1999), pp. 1–5

[10] J. Sim, C. Park, D.Y. Moon, Characteristics of basalt fibre as a strengthening material for concrete structures. Compos. B Eng. 36(6–7), 504–512 (2005)

[11] G. Wu, X. Wang, Z. Wu, Z. Dong, G. Zhang, Durability of basalt fibres and composites in corrosive environments. J. Compos. Mater. 49(7), 873–887 (2014)

[12] S.K. Kirthika, S.K. Singh, M. Surya, Durability studies of basalt fibre reinforced concrete. Indian Concr. J. 92(4), 45–55 (2018)