Comparative study of basalt fiber and steel fiber as additives to concrete

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Abstract. It is widely acknowledged that Basalt Fiber (BF) and Steel Fiber (SF) concrete possess a significant characteristic of superior resistance to cracking and crack propagation. This unique ability to arrest cracks results in fiber composites having enhanced extensibility and Ts, both at the initial crack and at the ultimate stage, particularly under flexural loading. Moreover, these fibers are capable of maintaining the integrity of the matrix even after extensive cracking. This research paper delves into the mechanical properties, technologies, and applications of BF and SFs. The study involved experimental investigations using M40 grade concrete mix, and tests were conducted in accordance with recommended procedures outlined in relevant codes. The laboratory experiments included the design of cubes, beams, and cylindrical specimens with varying percentages of BF and SF concrete ranging from 0% to 1.25% (0%, 0.25%, 0.5%, 0.75%, 1% and 1.25%). The obtained data was analyzed and compared with a control specimen (0% Fiber), and ultimately, the test results for BF and SF were compared. Additionally, a graphical representation was provided to illustrate the relationship between Cs, Fs, Ts, and Age i.e. 7 days and 28 days.

Key words: Fiber reinforced concrete (FRC), basalt fiber (BF) , steel fiber (SF) , compressive strength (Cs), Flexural Strength (Fs), and Split tensile strength (Sts)

1 Introduction

FRC plays a crucial role in the field of structural engineering applications. Concrete often faces exposure to high temperatures in the event of fire accidents or natural disasters. Despite being the most commonly used construction material, concrete does have certain limitations such as reduced strength, weight loss, shrinkage, and expansion.

Basalt rock, a type of volcanic rock, can be fragmented into small particles and then shaped into continuous or chopped fibers. It is formed from volcanic magma and flood

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volcanoes, which are extremely hot fluid or semi-fluid substances beneath the earth's crust that solidify upon exposure to the open air. Basalt, a gray, brown, or dark-colored volcanic rock, is created from solidified volcanic lava. Basalt fiber (BF) boasts a higher working temperature and exhibits excellent resistance to chemical corrosion, impact loads, and fire, emitting fewer toxic fumes.

2 Literature Review

A.Meher Prasad and Devdas Menon mentioned The main component of glass fiber reinforced gypsum (GFRG) wall panels is glass fibers reinforced into gypsum plaster. The panels can serve as load-bearing walls because they are hollow.

C. Selin Ravikumar and T.S. Thandavamoorthy reported that the incorporation of fibers in concrete has seen a notable rise to enhance the material's Ts and ductility. Moreover, fiber concrete is being used to retrofit existing concrete structures. Glass fiber is a recent inclusion among the diverse range of fibers utilized in concrete technology nowadays.

Deshmukh S.H., Bhusari J. P, Zende A. M: Cracking in concrete is a frequent occurrence caused by factors such as plastic and hardened states, drying shrinkage, and various other reasons. Concrete is known to be a building material with low Ts and susceptibility to fractures, as well as limited ductility.

Matthys S (2011) discovered that BF, a novel material in infrastructure engineering, can be used as an alternative to carbon, glass, and aramid for reinforcement. After conducting tests on the FRP confinement of columns, he concluded that BFs exhibit slightly superior qualities compared to glass fibers. Chemically, BFs are inert. Concrete is the most commonly used building material worldwide. Fibre-reinforced concrete (FRC), which consists of concrete with uniformly distributed tiny, discontinuous fibers, can be reinforced with various materials such as steel, glass, aramid, asbestos, polypropylene, jute, carbon, and steel.

Singaravadivelan et al. (2012) reported that the addition of BF resulted in a 25% improvement in the strength of the concrete. The literature review suggests that fibers, including BFs, are highly resistant to corrosion and environmentally friendly. BFs have the ability to withstand extreme temperatures and impact loads. Furthermore, basalt production requires less energy and is widely available. Despite being more expensive than BFs, both basalt and carbon offer exceptional mechanical and physical properties, making them a favorable choice for structural engineering. The study presented in this paper examines the effectiveness of BF concrete in compression, flexural, and split tensile tests conducted on cubes, cylinders, and beams..

Ranjitsinh K. Patil, D. B. Kulkarni :(2012) Various quantities of fibers (0.25%, 0.5%, 0.75%, and 1% of the total volume of concrete) were incorporated into the mix. A total of three cubes and three beams were formed for every fiber percentage to calculate the mean outcomes. Finally, a comparative analysis is presented for the three types of fibers at each percentage

G.K.Geethanjali :(2012) The study examined how the addition of BF and SP affects the compressive and Fss of fiber-reinforced concrete. Results from the experimental tests revealed notable enhancements in compression and Fs of the samples after 3, 7, and 28 days when BFs and SPs were incorporated. Concrete mixtures exposed to different stress conditions underwent nondestructive testing (NDT) methods like the Ultrasonic Pulse Velocity (UPV) test and the Rebound Hammer test.

Raghunath and K. Suguna conducted a study on the flexural behavior of reinforced concrete beams with high strength. In this study, all four beams, which had a length of 3 m and a cross-section of 150 mm by 250 mm, were cast and tested in a laboratory. Three different volumes of SF, namely 0.5%, 1%, and 1.5%, were used. Each beam underwent testing in a loading frame with a capacity of 750kn, under two-point load conditions.

Nayan Rathod, Mallikarjun Pujari, and Mukund Gonbare (2013) conducted a study utilizing cubes and concrete beams to showcase the variances in Cs and Fs between concrete containing BF and concrete without BF through experimental trials. The research highlights the wide range of potential applications of the material, the findings from the tests, and the comparison of BFRC's technology and cost with other materials, indicating its significant promise as a substitute for conventional construction materials

3 Materials and its Properties

3.1 Cement

The current study utilizes ordinary Portland cement 53 grade brand, which conforms to the standards established by the Indian Standards Institute (ISI). The cement is assessed for several characteristics as per the IS code.

Table 1. Physical Properties of cement

S. No	Property	Test results
1	Normal consistency	29%
2	Specific gravity	3.13
3	Initial setting time	92 minutes
4	Final setting time	195 minutes

3.2 Fine Aggregate

The fine aggregate used in this study consists of locally available sand, free from biological contaminants, salt, or clayey materials. Tests as per IS 2386-1963(28) have been carried out to assess its specific gravity, bulk density, and other properties. The grain size distribution of the sand suggests that it falls within the proximity of IS 383-1970 zone-I (29).

3.3 Coarse Aggregate

Locally sourced machine-crushed angular granite metal is used for the coarse aggregate, which may contain contaminants such as dust, clay particles, and other organic materials. Furthermore, various characteristics of the coarse aggregate are analyzed

3.4 BF

The main applications of basalt include its use in infrastructure, industry, and building. In addition to this, fibers like carbon, polyamide, and glass polythene are currently being developed and utilized in these sectors. A new type of fiber called "basalt rock fibers" has also been introduced. Basalt, which is a gray volcanic rock with various variations, is formed from highly hot, semi-fluid volcanic magma that emerges from flood volcanoes. It solidifies in the open air beneath the Earth's crust. The resulting volcanic lava is brown or dark-colored. Basalt possesses exceptional strength properties, including remarkable hardness and thermal qualities. Basalt fibers provide excellent strength and cost-effective performance, making them suitable for addressing challenges in large-scale projects such as concrete cracking and structural failure. The standard diameter typically falls within the 0.1 to 0.6 mm range for the BFs utilized in this project. The length of these BFs measures 12 mm, with a density of 2650 kg/cu.m.

Table 2. Chemical composition of BF

Chemical	%W	Chemical	%W
SiO_2	52.8	K_2O	1.46
Al_2O_3	17.5	TiO_2	1.38
Fe_2O_3	10.3	P_2O_5	0.28
MgO	4.63	MnO	0.16
CaO	8.59	Cr_2O_3	0.06
Na_2O	3.34		

3.5 SF

Various types of Steel fibers were utilized in this study. Steel fibers are short, distinct lengths of steel with an aspect ratio ranging from approximately 30 to 150, and with various cross-sectional shapes. Certain steel fibers feature hooked ends to enhance resistance to pullout from a cement-based matrix. These are the most frequently employed fibers. They have a round shape with a diameter of 0.25 to 0.75mm. They improve the flexural, impact, and fatigue strength of concrete

4 Experimental Investigations

This Experimental study was undertaken to investigate the Cs, Fs, and Sts of concrete at 7 and 28 days. Conventional Concrete of M40 Grade is used
Normal cement concrete (NCC) + 0% BF + 0% SF
NCC + 0.25% BF
NCC + 0.25% SF
NCC + 0.5% BF
NCC + 0.5% SF
NCC + 0.75% BF
NCC + 0.75% SF
NCC + 1% BF
NCC + 1% SF
NCC + 1.25% BF
NCC + 1.25% SF
NCC + 1.5% BF
NCC + 1.5% SF

5 Results and Discussions

5.1 Cs

The Cs of the concrete was determined by testing 150 x 150 x 150 mm cubes. The specimens were tested at both 7 days and 28 days, with three cubes tested for each mix on each specific day. The average value of the three specimens was recorded as the strength at that specific age. The Cs test was carried out for all the mixes, and the results are presented in the table provided below.

Table 3. Cs test results for BF concrete.

S.NO	% of BF	Cs(N/mm^2)	
		7 days	*28 days*
1	0%	33.9	49.12
2	0.25%	34.5	50.23
3	0.50%	35.9	53.2
4	0.75%	37.16	54.9
5	1%	35.14	52.1
6	1.25%	33.95	50.6

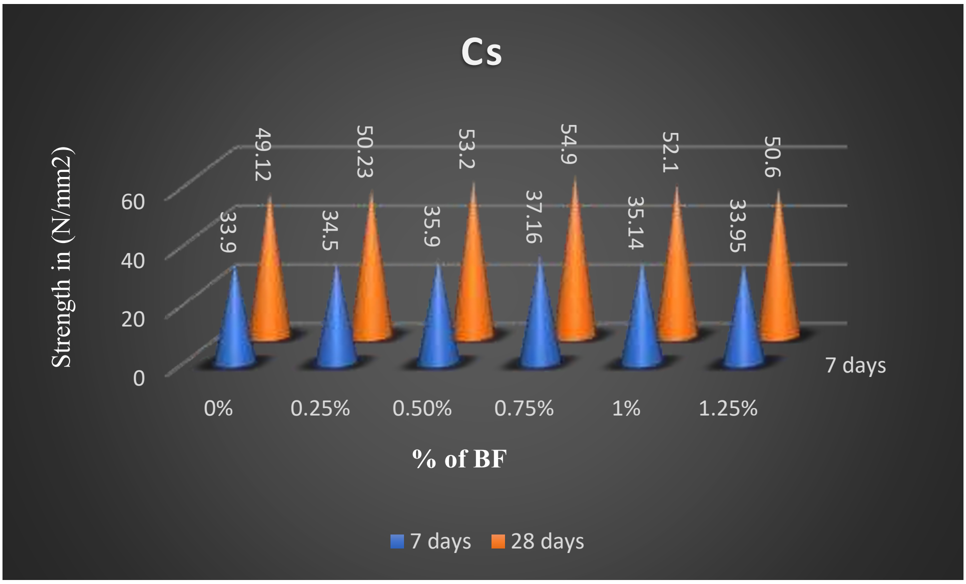

Fig 1. Cs Vs % of BF

Table 4. Cs test results for SF concrete.

S.NO	% of SF	Cs (N/mm^2)	
		7 days	*28 days*
1	0%	33.9	49.12
2	0.25%	32.6	49.96
3	0.50%	35.26	52.3
4	0.75%	37.2	53.18
5	1%	35.34	48.24
6	1.25%	32.12	47.92

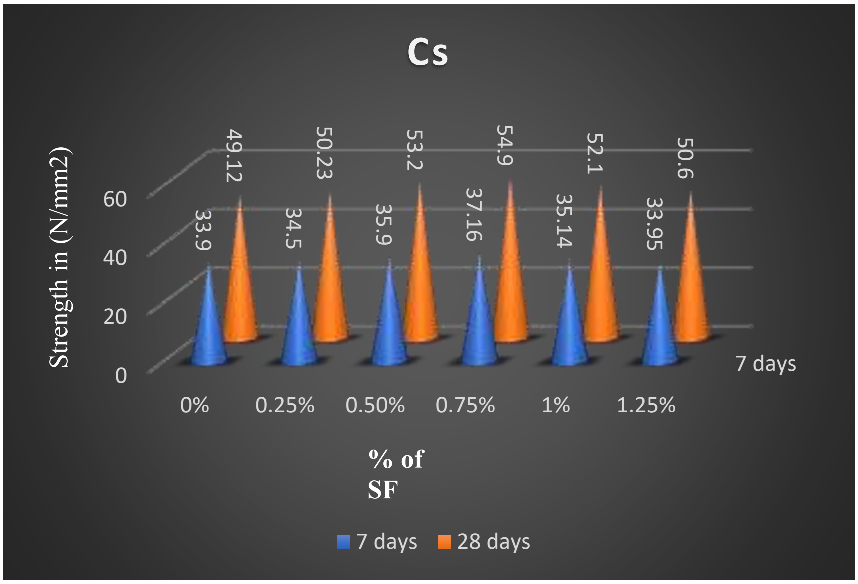

Fig 2. Cs Vs % of SF

The Cs of BF concrete at 0%, 0.25%, 0.5%, 0.75%, 1.0%, and 1.25% levels at 28 days has achieved the desired mean strength. Additionally, it was noted that the Cs increased by 2.26%, 8.31%, 11.76%, 6.07%, and 3.01% respectively when compared to NCC. The Cs has been observed to increase up to 0.75% in this parameter. However, beyond this threshold, the values show a decrease when compared to BF concrete. The inclusion of SF in concrete leads to an enhancement in the Cs of steel fibre by 1.7%, 6.47%, and 8.26% when added in proportions of 0.25%, 0.5%, and 0.75% respectively. However, the desired mean strength is not achieved when further steel fibres are added to the concrete mixture.

5.2 Sts

The indirect Tensile strength was gauged on 150 x 300 mm cylinders, and the results are outlined beneath

Table 5. Sts test results for BF concrete.

S.NO	% of BF	Split tensile strength(N/mm^2)	
		7 days	*28 days*
1	0%	2.1	4.79
2	0.25%	2.46	5.04
3	0.50%	2.8	5.48
4	0.75%	2.94	5.9
5	1%	2.72	5.24
6	1.25%	2.26	5.08

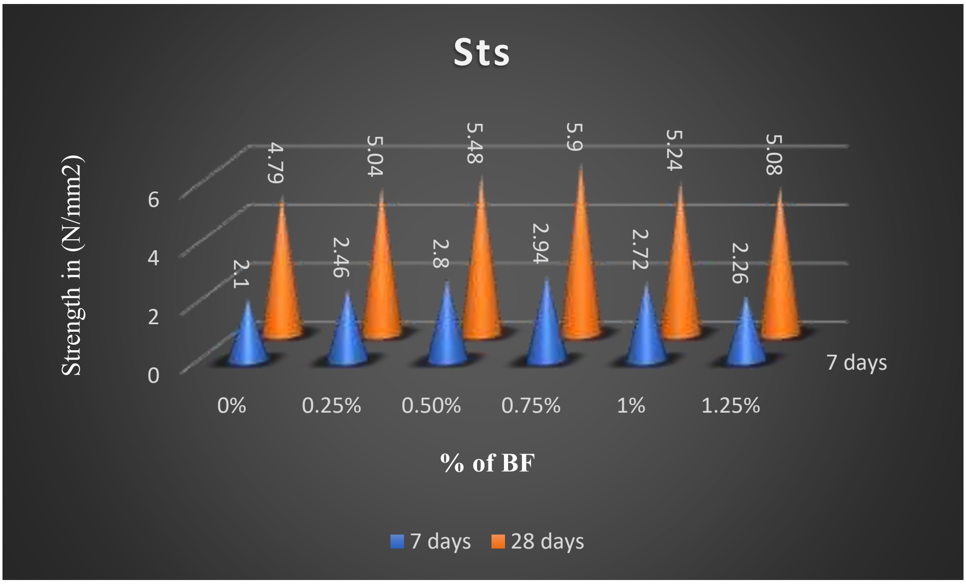

Fig 3. Ts Vs % of BF

Table 6. Ts test results for SF concrete.

S.NO	% of SF	Sts (N/mm2)	
		7 days	*28 days*
1	0%	2.1	4.79
2	0.25%	2.32	4.88
3	0.50%	2.44	4.98
4	0.75%	2.69	5.08
5	1%	2.9	5.36
6	1.25%	2.54	4.9

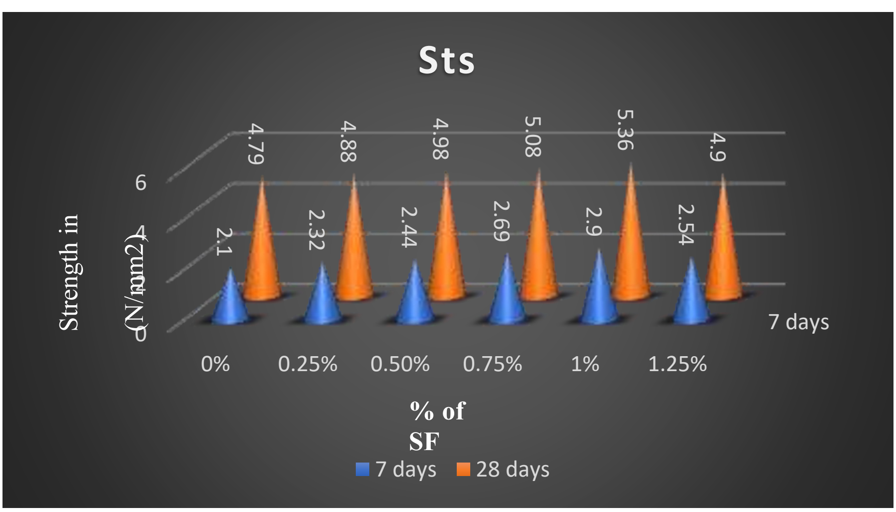

Fig 4. Ts Vs % of SF

The Sts of BF concrete at various percentages (0%, 0.25%, 0.5%, 0.75%, 1.0%, and 1.25%) after 28 days has been found to meet the desired mean strength. Interestingly, when compared to NCC, the Sts showed significant improvements of 5.21%, 14.40%, 23.17%, 9.39%, and 6.05% respectively. The Sts has been observed to increase up to 0.75% within this parameter. However, beyond this threshold, the values show a decrease when compared to BF concrete. The inclusion of steel fibers in concrete results in an increase in the Sts of SF by 1.88%, 3.97%, 6.05%, and 11.89% when added at rates of 0.25%, 0.5%, 0.75%, and 1% respectively. However, it should be noted that the strength of concrete decreases by 2.29% when steel fibers are added at a rate of 1.25%.

5.3 Fs

The Fs test was performed on beam specimens with dimensions of 150 x 150 x 750 mm to determine the Fs of the concrete

Table 7. Fs test results for BF concrete

S.NO	% of BF	Flexural strength(N/mm^2)	
		7 days	*28 days*
1	0%	3.11	5.33
2	0.25%	3.44	6.99
3	0.50%	3.91	8.97
4	0.75%	3.73	8.31
5	1%	3.54	7.52
6	1.25%	3.27	6.77

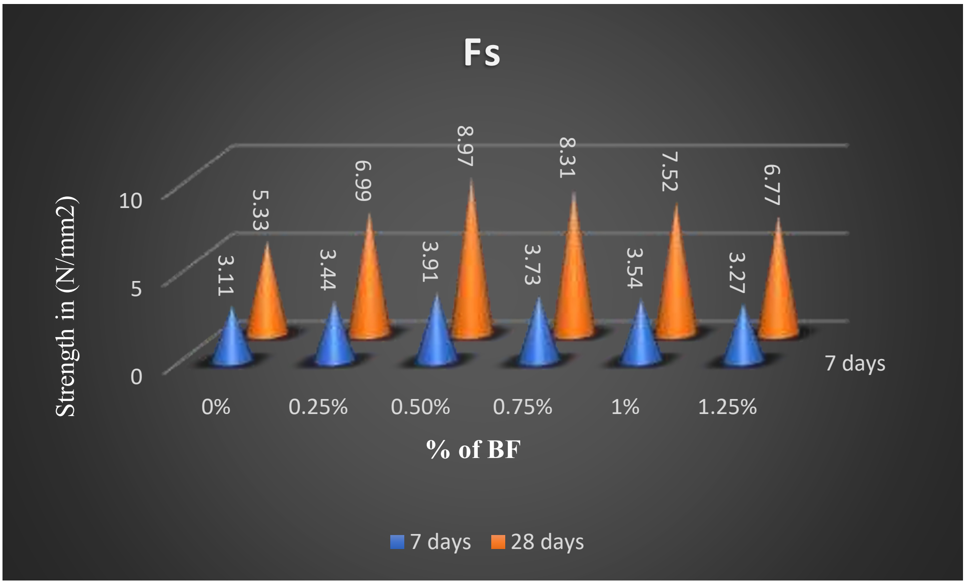

Fig 5. Fs Vs % of BF

Table 8. Fs test results for SF concrete

S.NO	% of SF	Flexural strength(N/mm2)	
		7 days	*28 days*
1	0%	3.11	5.33
2	0.25%	3.23	5.83
3	0.50%	3.51	6.25
4	0.75%	3.54	6.7
5	1%	3.89	7.24
6	1.25%	3.45	6.94

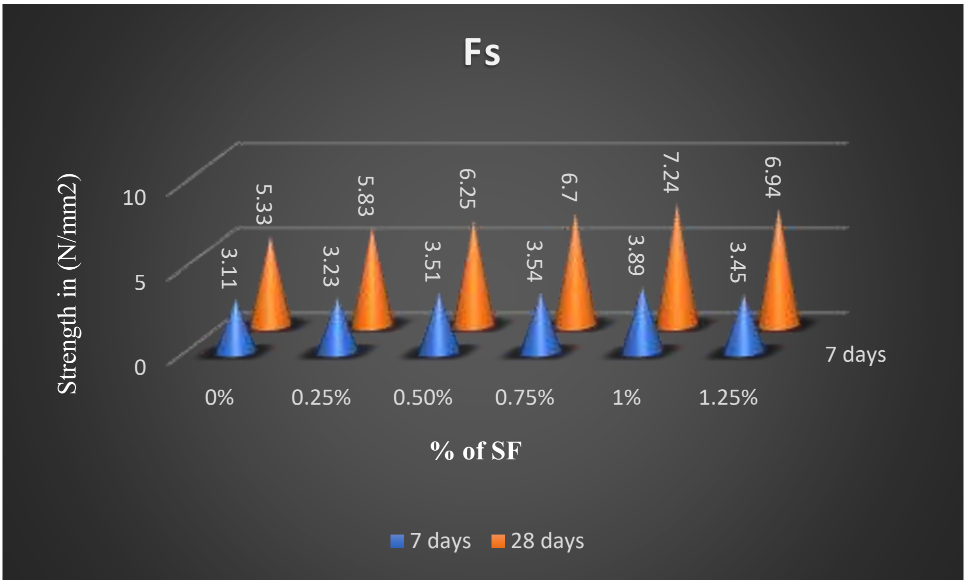

Fig 6. Fs Vs % of SF

The Fs of BF concrete at 0%, 0.25%, 0.5%, 0.75%, 1.0%, and 1.25% levels reached the target mean strength after 28 days. Conversely, the Sts showed an increase of 31.20%, 68.42%, 54.51%, 39.84%, and 27.06% respectively compared to NCC. Fs has been observed to increase in a linear manner up to 0.75% within this parameter. However, beyond this threshold, the values decrease when compared to BF concrete. The addition of steel fiber in concrete results in an increase in Fs by 7.71%, 19.17%, 27.82%, and 36.28% for 0.25%, 0.5%, 0.75%, and 1% respectively. However, when 1.25% steel fibers are added, the strength of concrete decreases by 30.64%.

6 Conclusions

1. The Cs, Sts, and Fs of the concrete were evaluated following a 28-day curing period in regular water. The concrete samples were subjected to weight additions of 0%, 0.25%, 0.5%, 0.75%, 1%, and 1.25% of basalt and SF.
2. The weight-based target mean strength has been enhanced to 0.75%. However, the Css of cement concrete with BF and SF additions at 1% and 1.25% are lower when compared to the regular concrete.
3. The mean strength target has been enhanced by 1% in terms of weight. However, when 1.25% BF and SF are added to the regular cement concrete, the split tensile and Fs are comparatively lower.
4. The statement above emphasizes the remarkable advantages of BF concrete over SF in terms of compression, split tensile, and Fs, showcasing its outstanding performance.
5. In comparing BF with SF, it is observed that deforms exhibit higher strength values than the latter. Additionally, the failure pattern of the specimens reveals that the formation of cracks is more prominent in concrete without fibers compared to BF reinforced concrete. This indicates that the inclusion of fibers in the concrete serves as crack arrestors.

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