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Mechanical properties of high strength concrete incorporating chopped basalt fibers: experimental and analytical study

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Abstract

Many civil engineering structures are constructed in terms of aspect like economy, strength and serviceability requirement. The fibres play a prominent role in bridging the micro cracks at the early stage of crack propagation and makes the structure ductile. The impact of chopped basalt fibre on high-strength reinforced concrete composites is the focus of this research. The chopped basalt fibre hardened property of concrete was investigated and compared it with controlled concrete. Moreover, physical property of concrete i.e. slump cone and compaction factor incorporating chopped basalt fibre volume fraction in variation of 0%, 0.75%, 1.5%, 2.25%, 3% to the total volume of concrete mix was also investigated. To analyse the hardened properties of chopped basalt fibre high strength concrete, 135 test samples were made and cured for 7, 14, and 28 days. The test findings show that increasing the volume percentage of fibres reduces slump from 135 mm to 132 mm for BFHS0.75 but does not result in a significant increase in concrete compressive strength of 77.1 MPa for BFHS0.75. However, on addition of chopped basalt fibres at 2.25% (BFHS2.25) the percentage increment of flexural strength increases by 72.8% (10.3 MPa) with control mix (5.96 MPa) and after that it decreases when 3% fibres were incorporated. Similarly, split-tensile strength increases at all fibre dosage and fibre addition of 3% (BFHS3) increases by 12.28% (5.65 MPa) with controlled concrete (5.04 MPa). The analytical results and suggested regression model could be used in real-world situations with fiber reinforced high strength concrete related issues. There is a significant relationship between mechanical property and independent variable through ANOVA in SPSS.

1. Introduction

High strength concrete is the requirement of today’s era as lots of multi-storey structures requires advanced materials to inculcate the need of the structure [1]. The use of high strength concrete in modern structures is increasing day by day due to reduced dead load of the structural columns which in turns reduce the cost [2]. High strength concrete possesses high compressive strength greater than 60 MPa as per Indian standard code. The material requirement for the high strength concrete includes silica fume, fly ash as mineral admixture which combines with chemical admixture to attain the required workability with low w/c ratio. Silica Fume (SF) acts as a prominent role in the hydration process of high strength concrete. As the concrete is having high strength which results into brittle behaviour so to reduce the brittleness the fibers are added together with concrete [3]. Different fibers are available like polypropylene, carbon, glass fibres etc but in this study the chopped basalt fibres are taken into consideration due to lack of research on chopped basalt fibres. Basalt fiber can be regarded as the eco-friendly and safe materials to be used. This is not a new material, but the application of it, it is no doubt to be innovative in a wide range of industrial and economic activities of energy-efficiency improvements to the building, from the automotive to the aerospace, aviation, due to the high mechanical, chemical and thermal properties. Therefore, basalt fiber (BF), it has received more and more attention to as a reinforcement of the...
material, especially when compared with the traditional glass fiber [4]. Basalt fibres are inorganic fibre originated from volcanic rocks which is having characteristics of resistance against acids, good thermal resistance etc [5]. The basalt fibres are having high energy absorption capacity. When the content of basalt fibres was increased, the workability of high strength concrete (HSC) based on slump value dropped [6]. According to Shafiq et al [7], Basalt Fibers (BF) can replace steel fibre, since they can be used to make lightweight cement compounds. According to Ahmed et al (2016), BF greatly increases the ductility of Fly ash/Magnesium Phosphate Cement (FA/MPC) composites. The composites with 1% of BF showed the highest compressive strength (CS) at roughly 77.6 MPa at 28 days, which was a relative increase of 25% over the standard control sample, according to Qing et al (2018). Furthermore, they showed that mixtures with more than 1% BF incorporation showed the compressive strength started to decline, which was caused by the increased development of pores within these solid compounds, and splitting tensile strength, Flexural Strength (FS), and Flexural Tension (FT) clearly found to increase with increase of BF contents. 59% & 108% split tensile strength was increased on addition of 0.75% and 1.5% basalt fibers. Additionally, Ahmed and Chen (2018) showed that the Magnesium Phosphate Cement (MPC) matrix 0.5% BF provided the highest compressive and flexural strength at 28 days, with values of 49.42 MPa and 5.31 MPa, respectively. Even yet, they [8] also noted an important point: there was a slight loss of strength for MPC mixtures with 0.75% BF as opposed to 0.5% BF. The answer for this reduced strength containing 0.75% BF was related to the flocculation tendency of BF at higher dosages. This is consistent with Kızılkanat et al (2015) research work. 12 mm & 24 mm basalt fibres length were investigated and tested for fresh and mechanical properties of concrete and the results were verified with ANOVA (statistical tool) to validate the results and it revealed that on changing the length of basalt fibres the workability, air content and compressive strength of concrete reduced [9]. The basalt fibres and Polyvinyl alcohol (PVA) fibres were taken to determine the mechanical properties of concrete and the results revealed that PVA fibres improved the property as compared to basalt fibre due to bridging ability of PVA [10]. There is a greater change in the post-peak residual strength of flexural performance of basalt fibre concrete as compared to control concrete [11]. Basalt fibre reinforcement for geopolymer concrete was researched by Xu et al (2021). The findings demonstrated that basalt fibre could improve the pores and raised the compressive and flexural strengths of geopolymer concrete when basalt fibre content was increased. The fiber-matrix transition zone benefited from the addition of basalt fibres, according to Saloni et al (2020) and the right amount of basalt fibres increased the concrete’s setting time and strength. Sahar A Mostafa et al (2022) studied their work on self-compacting concrete with basalt fiber addition for ultra-high-performance concrete and the behaviour of (Ultra-high-performance basalt fiber- self compacting concrete) UHPBF-SCC is also examined in this work in relation to increased temperatures of 300 °C and 600 °C. Studies were done on the physical characteristics, such as segregation resistance, flowability. They found that when nanoparticles are present, mechanical properties dramatically improve—by more than 18% in CS, 32% in TS, and 28% in FS when compared to the reference mix. Paschal Chimerezeze Chiadighikaobi et al (2022) worked on basalt fibres with light weight expanded clay composite and found that porosity index, CS and elastic modulus was improved when 1.6% BF was added to the mix. This paper is written to understand the characterization of chopped basalt fibers composite on high strength concrete in varying proportion by keeping the volume fraction of fibers limited to 3% of total volume of concrete. As other fibers such as steel, polypropylene, carbon fibers were used to study the behaviour of fiber reinforced concrete of normal strength & still there is an ample scope to utilize the chopped basalt fibers in high strength concrete and work on its analytical study. The objective of this study is to determine the mechanical properties of concrete and compare it with M70 grade of conventional concrete with analytical study.

1.1. Motivation of the research
The civil engineering structures are encountered by impact loads during their life span of structures which is very significant from strength criterion. Major contribution of basalt fibre as construction material in the pavement construction for better flexural strength and at the same time pavement requires very high strength concrete which is subjected to impact load of heavy vehicles. This is the prime motivation of doing this research. The application of fibres includes the design of high strength pavement for airport runway, off shore constructions, high rise buildings, bridges etc. The proposed research is limited to design of M70 grade of concrete as per IS 10262:2019 and the chopped basalt fibres are incorporated in variation of 0.75%, 1.5%, 2.25% & 3% by the volume fraction of total concrete mix.

1.2. Problem statement
Concrete faults become more noticeable as the service life lengthens, which causes numerous issues in engineering applications. As concrete ages, local failure mechanisms that regulate its ability to bridge are reduced bonding capacity, fibre pull-out, and fibre sliding. The linear elastic fracture mechanics form the foundation of the fibre spacing theory. It is believed that the concrete has flaws and microscopic fissures. The crack enlarges as a
result of the stress concentration created under the influence of the external force. By using fibre, the crack can be successfully stopped from spreading. This study represents the utilization of basalt fibres which greatly reduces the effect due to shrinkage in construction practices.

2. Experimental program

2.1. Selection of materials

In this design of high strength concrete with and without chopped basalt fibres with proper material characterization and their tests in the laboratory. Ordinary Portland Cement (OPC) of 53 grade refers to IS 269 was used to design high strength concrete. The cement was taken from Ultratech cement plant, Sahibabad, Ghaziabad. The maximum content of OPC is restricted to 450 Kg m$^{-3}$. The specific gravity of OPC was calculated as 3.15 and was determined from Le-Chatelier’s flask. The cement content for high strength was estimated as 427 kg m$^{-3}$. The specific gravity of fine aggregate in SSD condition is 2.65 and FA conforming to IS 383 belongs to grading Zone-II. The FA used to design high strength concrete is 588 kg m$^{-3}$. Fine aggregate was procured from Shiv building material supplier, Jhandapur, Ghaziabad. The specific gravity of Coarse aggregate in SSD condition is 2.74 and CA conforming to IS 383 and CA % different fraction of 10–4.75 mm & 20–10 mm is 50 & 50 respectively. Coarse aggregate was procured from Krishna stone crusher and supplier, New Delhi. Chopped Basalt fibres originated from volcanic rock is used in high strength concrete. The chopped basalt fibres are considered in the volume fraction of 0 to 3% of the volume of concrete with increment of 0.75%. Chopped basalt fibres are purchased from CF Composite, Dilshad Garden, New Delhi. Table 2 shows the property of chopped basalt fibre. Water/Cementitious ratio is a key parameter in deciding the strength of concrete. For high strength concrete the water-cement ratio is kept as low as normal strength concrete. Water-cementitious ratio of 0.3 is used in this study. Normal potable water is used throughout the research work. The primarily function of superplasticizer is to reduce the water content requirement and is used for high strength concrete. In this study, Auramix 400 chemical admixture made from Fosroc, chemicals India Pvt. Ltd, Bangalore was used based on polycarboxylic technology having advanced low viscosity with high performance and it is Poly-carboxylate ether

![Figure 1](image-url)
Figure 2. (a) Cylinder failure under CTM (b) Cube failure under CTM (c) 150 mm cube weight after curing (d) demolding of cube specimens (e), (f) Compaction factor measurement (g) 150 mm $\times$ 150mm $\times$ 700mm beam specimen (h) Beam specimen under universal testing machine for flexural strength.
based (PCE) type superplasticizer and the optimum dosage was determined from Marsh cone test and it reduces water content to 20%. Table 3 summarize the properties of Auramix 400. Fly ash powder of class F was used which is having great affinity during heat of hydration and it is purchased from Aditya enterprise, Surat, Gujarat. Amorphous silica fume which is a pozzolonic material and is purchased from the supplier Dalton mines and minerals, New Delhi.

2.2. Mix proportion
Total 5 mix groups were prepared and each mix designated as BFHS-0, BFHS.75, BFHS1.5, BFHS2.25, BFHS3 representing variation of chopped basalt fibres as 0%, 0.75%, 1.5%, 2.25%, 3% respectively by the volume fraction of total mix. The mix proportioning is done in accordance with Indian standards 10262:2019 [13] shown in table 1. 10 mm & 20 mm coarse aggregate were proportioned in the ratio of 50:50. The chopped basalt fibres were added in volume fraction of 0%–3% of total volume of concrete. The physical properties of basalt fibre as shown in table 2.

2.3. Mixing and specimen casting
Cement, fine aggregate, coarse aggregate, fly ash, silica fume is weighed and mixed together for dry mixing in concrete pan mixture for 2 to 3 min and then chopped basalt fibres were mixed by hand for dry mixing in concrete pan mixture then water is added along with the superplasticizer to obtain the required consistency of the concrete mix. The prepared concrete poured for workability test including slump test and compaction factor test. After that, moulds were properly oiled and concrete is poured in the moulds of cubes, cylinders and beams followed by compaction on vibrating machine to remove the voids in the mix and is allowed to dry for next 24 h. The dried samples were taken to curing tank for required age. It is clearly seen from table 4, that total number of specimens prepared for determining the hardened properties of high strength concrete were 135. The chopped basalt fibres in varying proportion were added and 45 cubes of size (150 mm × 150 mm × 150 mm) were prepared to determine the compressive strength at 7, 14 & 28 days of curing. Similarly, 45 beams (150 mm × 150 mm × 700 mm) & 45 cylinders (150 mm × 300 mm) were prepared to determine the flexural strength & split tensile strength of high strength concrete. Figures 1 and 2 shows the samples prepared.

Table 1. Mix proportioning and sample designation with varying % of Basalt fibres in Kg m
−3.

| S. no. | Mix ID | Cement | Fly ash | Silica Fume | Water | F.Aggr. | C. Agg. | Chemical admixture | w/cm | Vf(%) | BF in (Kg) |
|-------|--------|--------|---------|------------|-------|---------|---------|-------------------|------|-------|------------|
| 1     | BFHS-0 | 427    | 80.1    | 26.2       | 61.6  | 588     | 1218    | 2.66              | 0.30 | —     | —          |
| 2     | BFHS.75| 427    | 80.1    | 26.2       | 61.6  | 588     | 1218    | 2.66              | 0.30 | 0.75  | 19.7       |
| 3     | BFHS1.5| 427    | 80.1    | 26.2       | 61.6  | 588     | 1218    | 2.66              | 0.30 | 1.5   | 39.4       |
| 4     | BFHS2.25| 427   | 80.1    | 26.2       | 61.6  | 588     | 1218    | 2.66              | 0.30 | 2.25  | 59.1       |
| 5     | BFHS3  | 427    | 80.1    | 26.2       | 61.6  | 588     | 1218    | 2.66              | 0.30 | 3     | 78.9       |
Table 2. Properties of Basalt Fibres [12].

| Properties   | Values          | Length in mm (2 mm tolerance) | Diameter in μm (2 mm tolerance) | Aspect ratio (L/D) | Specific gravity | Elastic Modulus (GPa) | Tensile Strength (MPa) | Elongation at break (%) |
|--------------|-----------------|-------------------------------|---------------------------------|---------------------|------------------|-----------------------|------------------------|-------------------------|
|              | 12 mm           | 12                            | 0.5 mm                          | 1000                | 2.65             | 110                   | 3200                   | 3.50                    |
|              | 12 mm           | 12                            | 0.5 mm                          | 1000                | 2.65             | 110                   | 3200                   | 3.50                    |
|              | 12 mm           | 12                            | 0.5 mm                          | 1000                | 2.65             | 110                   | 3200                   | 3.50                    |
3. Test methodologies

3.1. Fresh state property of concrete
The fresh property of chopped basalt fibre reinforced concrete is done in accordance with IS: 1199-1959 for slump cone test and for compaction factor test. The slump value of fresh concrete with chopped basalt fibre was measured 135 mm which is satisfactory for the pumpable concrete and the compaction factor was 0.92 which shows that the workability of chopped basalt fibre composite is medium.

3.2. Compressive strength
Compressive strength of concrete is done in accordance with IS 516: 1959. The samples were taken out after 24 h from the curing tank and wipe with the cloth for testing the 15 cm × 15 cm × 15 cm cube in compression testing machine. The average of three samples were taken as the compressive strength of concrete. The load applied on the sample was continuously increasing at the rate of 309 kN min⁻¹ until the specimen fails.

3.3. Flexural strength
Hydraulic testing device was utilised to apply the stress on the sample. The load on specimen administered between 0.035 and 0.1 mm per minute. The peak load (P) was calculated using this test procedure and residual loads that account for the L/600 and L/150 deflection. The size of beam specimen taken is 150 mm × 150 mm × 700 mm because of 20 mm maximum size of aggregate. The testing procedure adopted for this flexural strength test on universal testing machine with loading rate of 3.924 kN min⁻¹ until the specimen fails. Equation (2) represents modulus of rupture for determining the strength.

\[ f = \frac{PL}{Bd^2} \]  

Where; 'L' is the length of beam, 'd' is the depth of beam, 'P' is the failure load, 'f' is the flexural strength.

3.4. Split tensile strength
According to ASTM C39 requirements, split tensile strength tests were performed on five cylinders for each type of mix. A 250 kN capacity universal testing equipment was used to test these specimens. 12 MPa min⁻¹ of loading every minute. 45 cylinders of basalt fibers in varying proportion were added in all the samples for testing. The size of the specimen used is 150 mm × 300 mm. The splitting tensile test was loaded at a rate of 0.7 to 1.4 MPa min⁻¹ till failure. According to ASTM C496 criteria, the average of the three specimens were taken as the split tensile strength of concrete as per formula given in Indian standard.

\[ fst = \frac{2P}{\pi DL} \]  

Where; L is the length of cylinder, D is the diameter of cylinder, P is the failure load, fst is the Split Tensile strength.
4. Results and discussion

The results of workability, mechanical property for high strength concrete with chopped basalt fibres is discussed. Regression models were developed & validated in subsequent section.

4.1. Effect of chopped basalt fibres on workability

Figure 3 represents the findings and reveal that on increasing the volume percentage of fibres it reduces slump. When chopped basalt fibres added in concrete the slump decreases on increasing fibre percentage and this trend is seen throughout the research work. The slump cone of BFHS-0 was found to be 135 mm in which no chopped basalt fibres were added in the mixture. For the mix BFHS-0.75 the value of slump cone measured was 132 mm and follows the same trend for subsequent mixes of BFHS-1.5, BFHS-2.25, BFHS-3 with the slump value 128 mm, 123 mm and 115 mm respectively. This reduction is due to accumulation of fibres that changes water-binder ratio and also due to the huge surface area of CBF, when more basalt fibre is added, resulting in a reduction in slump. Green concrete’s workability is dependent on its proper placement and the mixture’s subsequent performance. Mixing ratio and moisture content are the prominent factors that affects the workability. Jianxun Ma [14] also observed the influence of pre-soaking basalt fibre on concrete quality, as well as the fact that the workability of mixtures containing basalt fibre decreases as the amount and length of basalt fibre increases. Tumadhir [15] also looked at the impact of different basalt fibre contents on reinforced concrete workability and suggest the same pattern of slump value. Similar research Singaravadivelan R [16] and Wang X et al [17] found that when the fibre content of concrete rises, the workability of freshly formed concrete with varying basalt fibre content diminishes. The research reported [18–21] that flow decreases as the fibre dosage and length of the fibre rises.

4.2. Effect of chopped basalt fibres on compressive strength

There is a negligible change on concrete compressive strength on 0.75% fibres and it reduces with increase in fibre dosage up to 3%. It is clear from the table 4 and figure 4 that average compressive strength at 28 days for control concrete (BFHS-0) is 76.8 MPa. Incorporation of 0.75% chopped basalt fibres the compressive strength remains the same and further on addition of 1.5% the average strength starts decreasing by 2.86% than control concrete. BFHS3 indicating compressive strength decreases by 3.33% than control concrete. Since presence of fibres in compression does not increase appreciably since the failure is in compressive direction and not due to fracture. Another reason is that the cohesiveness among cement paste & aggregate deteriorated due to the basalt fibres and at the same time due to very less diameter of CBF, it starts vanish during mixing and flocculated together and fibres bridging behaviour lacking which in turns reduces the compressive strength and increases the brittleness [22–25]. The increased fibre dosage in cubes shows there is a decrease in the crack width, although compressive strength in terms of load carrying capacity do not meet the requirement [19, 26–28]. Tumadhir and Borhan [15] found similar results on different percentage of fibres and reported that influence of basalt fibres is very less on compressive strength. Wang and Zhang

![Average Compressive Strength in MPa](image)

Figure 4. Average compressive strength with various mix designation.
and Revade [30] also support the similar trend during their research. This could be due to increased fibre dosage in the mixture, which produces voids, reducing ITZ between fibers and other constituents.

4.3. Effect of chopped basalt fibres on split tensile strength

Table 5, figure 6 and 7 shows the average split tensile strength, peak load and percentage increment with standard concrete at 28 days. The split tensile strength with 0% fibres was 5.04 MPa and it was not changed on increasing 0.75% fibres. Further on addition of 1.5% dosage of CBF the split-tensile strength increases by 5.55% than control concrete and the peak load was 376.04 kN. Similarly, on 3% fibre dosage the strength enhances by 12.28% & the peak load notice was 400 kN for mix designation BFHS3 and also maximum strength was achieved at 3%. With fibre fraction rises the spalling of concrete increase and also cracking resistance increases which results in improved ductility [31–33]. Revade [30] also found the similar pattern in his research work on adding 1–1.5 percent fibres split tensile strength increases because of high tensile property of CBF. Similar study was observed by Ketan [34] and Chen Feng [35], adding 1% basalt fibre to concrete reduces tensile strength. The only reason is the increased dosage of CBF and length, and at the same time remarkable balling effect was observed and it reduces fibre bridging in concrete. Figures 5 and 8 shows the failure pattern. Figure 11(a) shows the failure pattern. Figure 11(a) shows the failure pattern of split tensile strength.

4.4. Effect of chopped basalt fibres on flexural strength

Table 6, figures 9 and 10 shows average flexural strength and % increase with control concrete at 28 days. The flexural strength with 0% fibres was 5.96 MPa and on increasing 0.75% fibres it increases by 15% for BFHS.75. Further on addition of 1.5% volume fraction of chopped basalt fibres the flexural strength increases by 41.9% than control concrete. Similarly, on increasing dosage of fibres to 2.25% the average flexural strength was 10.3 MPa, increases by 72.8% & was maximum for mix designation BFHS2.25 and also 2.25% found the optimum dosage of fibres in split tensile strength. As with fibre addition of 3% the flexural strength starts decreasing. Bridging action of fibres plays an important role in restrict the growth of cracks up to 2.25% fibre fraction and improves ductility [36–38] and the effect of chopped basalt fibres at 3% was insignificant. Basalt fibres were added to the concrete mix and compared to regular concrete. When basalt fibre is added properly, cement paste and aggregates are uniformly distributed; however, when basalt fibre is added excessively, more cement paste bonds to the fibre, weakening the bond between the aggregates and cement paste as a result of the reduced amount of cement paste on the aggregates. The several authors Wang and Zhang [29], Ketan [34],

![Figure 5. (a) Failure pattern of BFHS-0 & (b) Failure pattern of BFHS0.75.](image-url)
Solikin [39] used prisms to evaluate the flexural strength of numerous specimens and found the same pattern in flexural strength. Figure 11(b) shows the failure pattern of flexural strength.

4.5. Regression model developed between split tensile strength and flexural strength

\[
ST = 0.13337 \times FS + 4.22
\]

\[
FS = 5.618 \times ST - 21.663
\]

Regression model is developed between ST (Split tensile strength) and FS (Flexural Strength) in equations (3) and (4). Figure 12 shows the experimental versus predicted split tensile strength and figure 13 shows the experimental versus predicted flexural strength.

4.6. Regression model developed between compressive strength and split tensile strength

\[
CS = -4.4151 \times ST + 98.85
\]

\[
ST = -0.19943 \times CS + 20.348
\]
Figure 8. (a) Failure pattern of BFHS-0 & (b) Failure pattern of BFHS3

Figure 9. Average flexural strength at 28 days with various mix designation.

Table 6. Average Split-Tensile strength & Peak Load for 28 days of curing.

| S. no. | Mix ID | Split-Tensile strength (MPa) at 28 days | Peak Load (kN) | % Increase in strength than control mix |
|--------|--------|----------------------------------------|----------------|----------------------------------------|
| 1      | BFHS-0 | 5.04                                   | 356.25         | —                                      |
| 2      | BFHS.75| 5.04                                   | 356.25         | 0%                                     |
| 3      | BFHS1.5| 5.32                                   | 376.04         | 5.35%                                  |
| 4      | BFHS2.25| 5.47                                   | 386.65         | 8.33%                                  |
| 5      | BFHS3  | 5.65                                   | 400            | 12.28%                                 |
Figure 10. % Increase in flexural strength at 28 days with various mix designation.

Figure 11. (a) Cross section view of failure pattern BFHS 3 under CTM & (b) Failure pattern of BFRC 2.25 under flexure.

Figure 12. Experimental Split tensile strength versus Predicted Split tensile strength.
Regression model is developed between CS (Compressive strength) and ST (Split tensile strength) in equations (5) and (6). Figure 14 shows the experimental versus predicted Compressive strength and figure 15 shows the experimental versus predicted split tensile strength.

4.7. Multiple regression analysis on compressive strength, flexural strength and split tensile strength

Multiple regression analysis is analyzed for all the mechanical properties and other variables like, cement, fine aggregate, coarse aggregate, water/cementitious ratio, fly ash, silica fume, water, chemical admixture, Vf (%), Basalt fibre (BF). The principle of analysis is that the ANOVA test is used to analyze the differences among the means of various groups using certain estimation procedures. ANOVA means analysis of variance. ANOVA test
is a statistical significance test that is used to check whether the null hypothesis can be rejected or not during hypothesis testing.

(i) Multiple Regression analysis for Compressive strength.

**Null hypothesis (H0):** There is no significant relationship between compressive strength and other variables.

**Alternate hypothesis (H1):** There is a significant relationship between compressive strength and other variables.

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**Model Summary of compressive strength**

| Model | R     | R Square | Adjusted R Square | Std. Error of the Estimate |
|-------|-------|----------|-------------------|---------------------------|
| 1     | .903* | .816     | .755              | .62436                    |

* Predictors: (Constant), X10.
ANOVA*

| Model | Sum of Squares | df | Mean Square | F     | 5% F-Critical (Table Value) |
|-------|----------------|----|-------------|-------|----------------------------|
| 1     | Regression     | 5.183 | 1 | 5.183 | 13.295 | 10.13                      |
|       | Residual       | 1.169 | 3 | .390  |              |                           |
| Total |                | 6.352 | 4 |       |              |                           |

* Dependent Variable: Compressive Strength.
* Predictors: (Constant), X10.

From model summary of compressive strength, it is very clear that R Square value is 0.816 and Adjusted R Square is 0.755 which is close to 1. In addition to this, ANOVA table shows that F-value i.e., 13.295 is greater than F- critical i.e., table Value (10.13) at 5% level of significance. This signifies that null hypothesis (Ho) is rejected and alternate hypothesis (H1) is accepted. Therefore, there is a positive significant relationship between compressive strength and other variables.

(i) Multiple Regression analysis for Split tensile strength.

**Null hypothesis (Ho):** There is no significant relationship between ST strength and other variables.

**Alternate hypothesis (H1):** There is a significant relationship between Split tensile strength and other variables.

Model Summary of Split-Tensile strength

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|-------|---|----------|-------------------|---------------------------|
| 1     | .974* | .949    | .932             | .06987                    |

* Predictors: (Constant), X10.

ANOVA*

| Model | Sum of Squares | df | Mean Square | F     | 5% F-Critical (Table Value) |
|-------|----------------|----|-------------|-------|----------------------------|
| 1     | Regression     | .272 | 1 | .272  | 55.781 | 10.13                      |
|       | Residual       | .015 | 3 | .005  |              |                           |
| Total |                | .287 | 4 |       |              |                           |

* Dependent Variable: Split tensile strength.
* Predictors: (Constant), X10.

From model summary of Split-tensile strength, it is very clear that R Square value is 0.949 and Adjusted R Square is 0.932 which is close to 1. In addition to this, ANOVA table shows that F-value i.e., 55.781 is greater than F- critical i.e., table Value (10.13) at 5% level of significance. This signifies that null hypothesis (Ho) is rejected and alternate hypothesis (H1) is accepted. Therefore, there is a positive significant relationship between Split-tensile strength and other variables.

(iii) Multiple Regression analysis for Flexural strength.

**Null hypothesis (Ho):** There is no significant relationship between Flexural strength and other variables.

**Alternate hypothesis (H1):** There is a significant relationship between Flexural strength and other variables.

Model summary of flexural strength

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|-------|---|----------|-------------------|---------------------------|
| 1     | .884* | .781    | .708             | .93956                    |

* Predictors: (Constant), X10.
From model summary of Flexural strength, it is very clear that R Square value is 0.781 and Adjusted R Square is 0.708 which is close to 1. In addition to this, ANOVA table shows that F-value i.e., 10.714 is greater than F-critical (10.13) at 5% level of significance. This signifies that null hypothesis (Ho) is rejected and alternate hypothesis (H1) is accepted. Therefore, there is a positive significant relationship between Flexural strength and other variables.

5. Conclusion

• Within the parameters of this investigation, the ideal volume fraction of basalt fibres is between 2.25% and 3%. Concrete’s flexural strength and split tensile strength have all greatly increased in this instance. The mechanical characteristics of basalt fibre are diminished when the volume fraction exceeds the ideal volume fraction.

• Presence of fibres in compression does not increase appreciably since the failure is in compressive direction and not due to fracture.

• Bridging action of fibres plays an important role in restrict the growth of cracks up to 2.25% fibre fraction and improves ductility and the effect of chopped basalt fibres at 3% was insignificant in flexure.

• Regression models were developed to predict the compressive strength, flexural strength and split tensile strength of concrete with addition of chopped basalt fibre. The analytical results and suggested regression model could be used in real-world situations with fiber reinforced high strength concrete related issues.

• There is a positive significant relationship between compressive strength and other variables like, cement, fine aggregate, coarse aggregate, water/cementitious ratio, fly ash, silica fume, water, chemical admixture, Vf (%), Basalt fibre (BF) through ANOVA. Similarly, for split tensile strength and flexural strength.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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