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Investigation on Basalt Based High Performance Concrete

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Abstract

The study aims to explore the potential of basalt fibers and metakaolin in enhancing the mechanical, durability, and microstructural characteristics of concrete. The investigation begins with a thorough literature review is conducted to ascertain the present status of information regarding metakaolin, basalt fibers, and their impact on concrete. The experimental program involves the formulation of concrete mixtures with varying percentages of basalt fibers and metakaolin, alongside a control mixture without these additions. At various stages of the curing process, mechanical attributes such split tensile strength and compressive strength are assessed. The results are compared with the control mixture to assess the influence of basalt fibers and metakaolin on the strength development of HPC. The aim is to determine the effectiveness of basalt fibers and metakaolin in enhancing the resistance of HPC to environmental degradation factors. The research findings reveal that the inclusion of basalt fibers and metakaolin in high-performance concrete leads to improvements in mechanical properties, such as increased compressive strength, and split tensile strength.

Keywords: Basalt fibers, Metakaolin, Mechanical Properties, Durability and High Performance Concrete etc.

INTRODUCTION

High performance concrete (HPC), when compared to regular concrete has improved mechanical qualities, durability, and sustainability. The development of HPC involves the incorporation of various supplementary cementitious materials (SCMs) and fibers to enhance its performance [1–3]. Basalt fiber and metakaolin are two commonly used materials in the production of HPC due to their favorable properties. One kind of mineral fiber that comes from the fine fibers of basalt rock is called basalt fiber. It possesses excellent mechanical properties, such as high tensile strength, good resistance to alkaline environments, and high durability [4–7]. These properties make basalt fiber a suitable reinforcement material for concrete, enhancing its strength and crack resistance. Metakaolin, on the other hand, is a pozzolanic material obtained by calcining kaolin clay at high temperatures. It is widely used as an SCM in concrete production due to its pozzolanic activity, which leads to improved strength, reduced permeability, and enhanced durability of concrete [8–10]. Metakaolin also contributes to the production of more sustainable concrete by reducing the need for cement, which helps in mitigating carbon dioxide emissions associated with cement production [10–13]. Adding 20–60 mm of basalt fiber to concrete that replaced partially with GGBS will enhance the tensile strength by a maximum of 69% in plain concrete and by a maximum of 50% in GGBS concrete [14]. Ibrahim Yasser E. and others [15] showed enhancement in tensile strength by adding up to 2%

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DPF. This was seen because, at three, seven, and twenty eight days, M1F0S's tensile strength was 5.3%, 8.9%, and 12.6% greater than the control's. The M2F0S tensile strength was superior to the control by 11.5% and 16.6%, respectively, at seven and twenty eight days. This rise in strength was attributed to the arrest of crack caused by the fiber bridging action and energy transfer from the fibres. As a result, the tensile strength and post-cracking load resistance were both increased [16]. According to testimony by Jamshaid and Mishra [17] additional fibres such coconut, sisal, jute and sugarcane fibres were discovered to boost the concrete tensile strength. The tensile strength of the composite was nevertheless decreased by the 3% DPF addition; however, for M3F0S, the strength was 15%, 7.2%, and 14.6% lower than at 3, 7, and 28 days, respectively. This could be a result of the poor fibers dispersion and effect due to balling due to addition to trapping air during mixing on the fibre surface, enhanced the porosity of the cement matrix. The decrease in tensile strength as a result of the weak and discontinuous route that resulted in early failure upon application of the load. Deficit of appropriate adhesion between and cement matrix and DPF could be another explanation. The addition of silica fume improved the splitting tensile strength of the concrete much further. By replacing 5% and 10% of the cement with silica fume, it was possible to effectively counteract the detrimental effects of the addition of 3% DPF on the tensile strength of the DPF-reinforced concrete. A. B. Kizilkanata and colleagues [18] examined the characteristics of cured concrete containing 12 mm basalt fibre at various contents (0.25%, 0.50%, 0.75%, and 1.0%) by total volume. They come to the conclusion that a 1% dose of basalt fiber increases the flexural strength by 34% in contrast to conventional concrete. The durability and concrete strength incorporating varied length basalt fibres of 12, 36 and 50 mm at varying dosage of 4, 8, and 12 kg/m 3 were studied by Padmanabhan Lyer and his colleagues [19].

EXPERIMENTAL INVESTIGATION

Test Specimens

In this study, 150*150*150 mm size cubes and 300*100 mm size cylinder are casted. The binder content taken are metakaolin and silica fume which are activated by using polycarboxylate either based activators. When casting, the mixing of the binders must be done properly and should be thoroughly mixed in order to obtain uniform composition. Following are the casting of bricks, casting is completed at REVA University in Concrete Laboratory as shown in Figure 1.

Material Properties

The experimental materials are outlined in this chapter. The description of the material's characteristics follows:

Figure 1. Casted Cubes done on REVA University.

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The ingredients used for making the basalt based high performance concrete are:

- *Binding Agents:* Metakaolin and silica fume
- *Cement:* OPC 58 grade
- *Fine Aggregates:* M sand.
- *Coarse Aggregates:* 10 mm to 20 mm
- *Fibers:* Basalt fibers of 6 mm size
- *Poly carboxylate either based super plasticizer:* Infra plus.

Metakaolin

A pozzolanic mineral additive called metakaolin is used to improve the qualities of cement-based materials like concrete. It is produced by thermally activating ordinary clay or kaolinitic clay at temperatures between 600 to 800 degrees Celsius, which leads to the transformation of the clay minerals into a reactive amorphous material. The use of metakaolin in concrete offers several benefits. It significantly improves the early strength development of concrete, allowing for faster setting and hardening. Metakaolin enhances the durability of concrete by reducing permeability.

Silica Fume

The finely powdered substance known as silica fume, or micro silica, is a byproduct of the production of silicon and ferrosilicon alloys. Unlike crystalline forms, silica fume has an amorphous structure and consists of tiny spherical particles with an average diameter of 150 nanometers. This unique material possesses excellent pozzolanic properties and is used in concrete to enhance its strength, durability, impermeability, and resistance to chemical attack. By filling the gaps between cement particles, silica fume improves the density and overall performance of concrete. Its utilization contributes to sustainable construction practices by reducing the need for cement and lowering carbon dioxide emissions.

Basalt Fibers

Basalt fiber, derived from molten basalt rock, is an inorganic fiber that can be readily found in the commercial market. Unlike other fibers, it is free from any additives. Notably, basalt fiber exhibits superior tensile strength compared to glass fibers and boasts greater failure strength than carbon fibers. Its impressive resistance to chemical attack and impact loads further enhances its appeal as a potential replacement for other fiber.

MATERIAL MIX DESIGN

The mix proportioning for different percentage of binder proportions has been made based on the little prior research on sustainable concrete that is currently accessible and is as given Table 1.

Table 1. Percentage replacement of Metakaolin and silica fume

Percentage replacement of Metakaolin and silica fume				
Parameters	5%	10%	15%	20%
Cement(kg/m^3)	497	471	445	419
Metakaolin and Silica fume(kg/m^3)	26.15	52.3	78.45	104.6
Water(kg/m^3)	157	157	157	157
Fine aggregate(kg/m^3)	657	657	657	657
Coarse aggregate(kg/m^3)	1247	1247	1247	1247
Chemical admixture(kg/m^3)	5.23	5.23	5.23	5.23

RESULT AND DISCUSSIONS

The compression test and the split tensile test conducted as shown in Figure 2 (a) and (b) respectively. The results obtained from the experimental data are discussed below

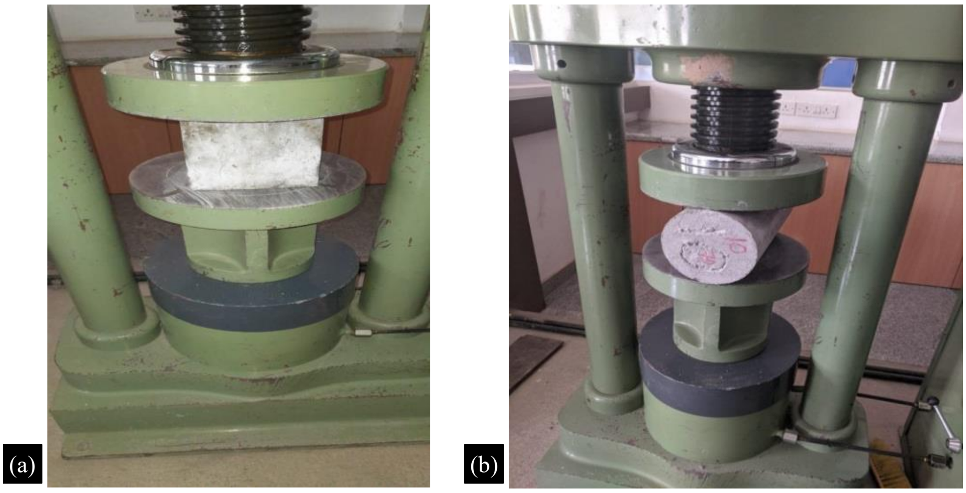

Figure 2. Experimental set up (a) For compression test (b) For split tensile test.

Compressive Strength Test

The compressive strength of concrete plays a vital role in assessing their resilience against compression forces and their ability to withstand such pressures without fracturing or failing as shown in Figure 2 (a). It represents the maximum load or force that a concrete cubes can bear before reaching its breaking point. From Figure 3, Figure 4 and Figure 5 shows that after 28 days of curing, the highest compression strengths of 60.74 MPa and 61.43 MPa were achieved using 15% Metakaolin and 10% Silica fume, respectively. Additionally, the experiment was expanded by adding basalt fiber with15% Metakaolin, and the highest maximum compression strength of all the experiments 68.92 Mpa was found as given in Tables 2–4, Figures 3–5.

Table 2. Compressive strength test for metakaolin.

% of metakaolin % O	7 DAYS Strength N/mm^2	14 DAYS Strength N/mm^2	21 DAYS Strength N/mm^2	28 DAYS Strength N/mm^2
5%	33.48	42.66	47.85	52.85
10%	32.44	38.22	35.07	55.33
15%	41.03	50.96	41.62	60.74
20%	24.74	37.38	40.74	38.11

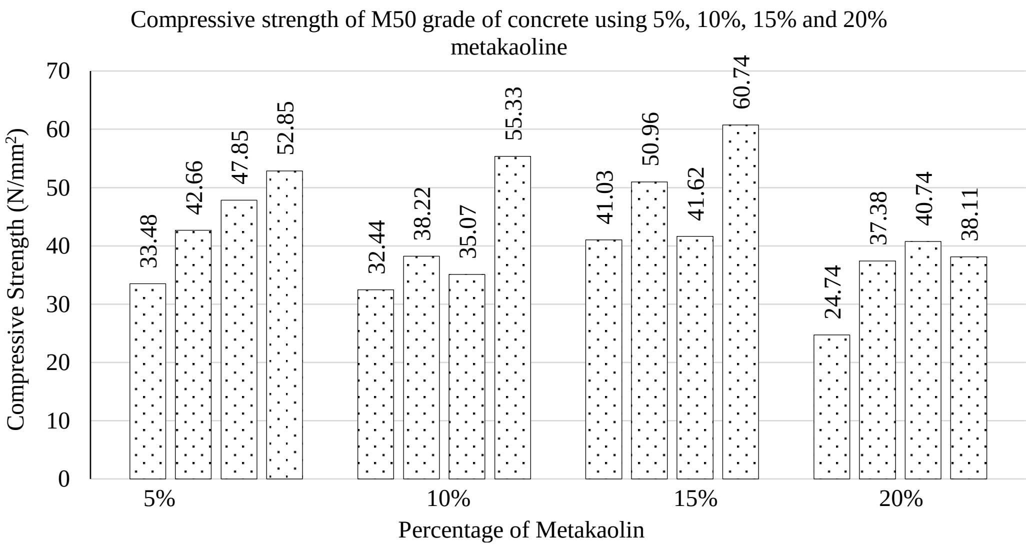

Figure 3. Compressive strength v/s percentage of metakaolin.

Table 3. Compressive strength test for silica fume.

% of Silica Fume	7 Days N/mm^2	14 Days N/mm^2	21 Days N/mm^2	28 Days N/mm^2
5%	41.91	42.21	43.10	44.81
10%	36.72	59.68	48.23	61.43
15%	41.9	44.44	53.40	55.52
20%	45.32	46.81	43.10	47.84

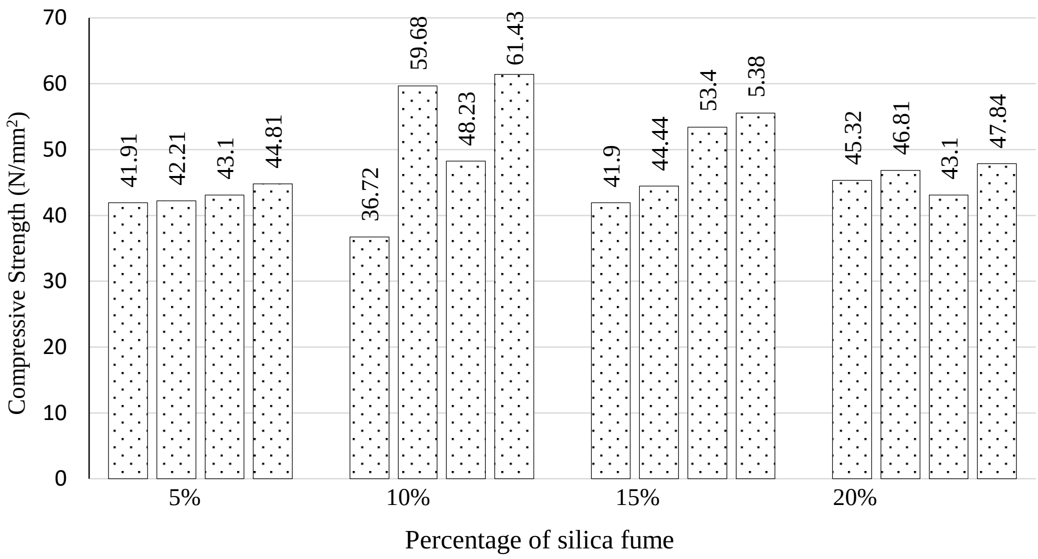

Figure 4. Compressive strength v/s percentage of silica fume.

Table 4. Compressive strength test for 15% metakaolin and basalt fiber (6 mm).

Days	Strength N/mm^2
7	38.36
14	53.04
21	57.73
28	68.92

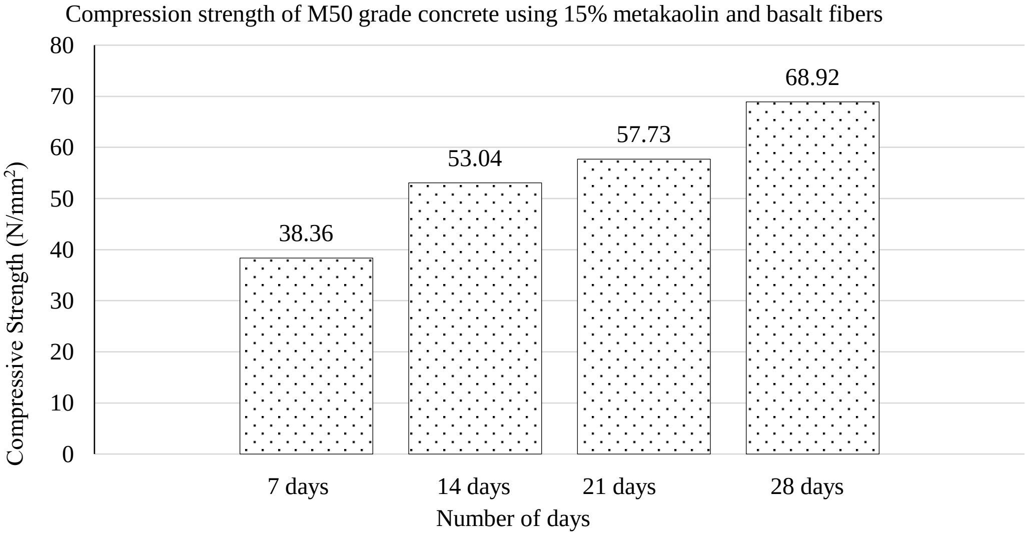

Figure 5. Compressive strength test for 15% metakaolin and basalt fiber (6 mm).

Split Tensile Strength Test

To ascertain the tensile strength of concrete or other brittle materials, a split tensile test also referred to as a Brazilian test or an indirect tensile strength test is employed. In this test, a cylindrical specimen of size 300*100 mm is subjected to a diametrical compressive load until it fractures as shown in Figure 2. (b). The test determines the material's tensile strength perpendicular to the applied load. From Figure 6 and Figure 7 shows that after 28 days of curing, the highest split tensile strengths of 5.38 MPa and 5.41 MPa were achieved using 15% Metakaolin and 15% Silica fume, respectively as shown in in Tables 5 & 6, Figures 6 &7.

Table 5. Split tensile strength test for metakaolin.

% of Metakaolin	7 days N/mm^2	14 days N/mm^2	21 days N/mm^2	28 days N/mm^2
5%	3.77	4.36	4.71	5.14
10%	3.25	3.81	4.60	5.01
15%	4.10	4.52	4.92	5.38
20%	3.15	3.77	5.37	4.89

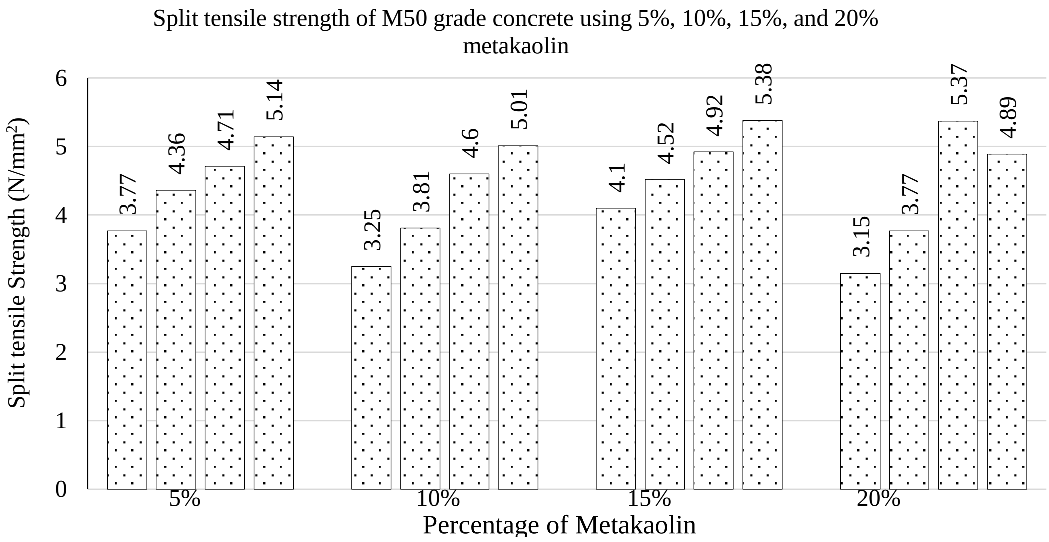

Figure 6. Split tensile strength v/s percentage of metakaolin.

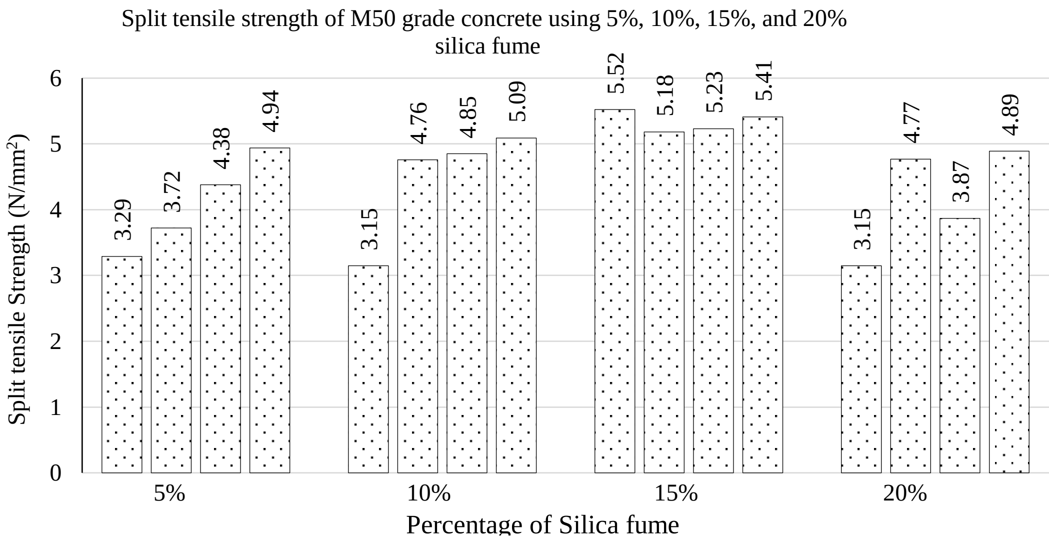

Figure 7. Split tensile strength v/s percentage of silica fume.

Table 6. Split tensile strength test for silica fume.

% of Silica Fume	7 days N/mm^2	14 days N/mm^2	21 days N/mm^2	28 days N/mm^2
5%	3.29	3.72	4.38	4.94
10%	4.52	5.18	5.23	5.41
15%	3.15	4.76	4.85	5.09
20%	3.15	4.77	3.87	4.89

CONCLUSIONS

According to the findings of the study, the following conclusions were drawn:

The utilization of silica fume and metakaolin as by-products in cement and concrete has emerged as a vital practice need for environmental preservation and sustainable construction in the future.

Over time, the compressive strength of normal concrete increased gradually, peaking at 52.88 N/mm^2 after 28 days. Similarly, the split tensile strength exhibited a positive progression, with the highest value of 3.03 N/mm^2 observed at 28 days.

The introduction of metakaolin into the concrete mixture had a discernible impact on both compressive and split tensile strengths. Incremental additions of metakaolin demonstrated a proportional improvement in strength properties. Notably, the 15% metakaolin content exhibited the highest compressive strength of 60.74 N/mm^2 after 28 days. Additionally, the split tensile strength peaked at 5.38 N/mm^2 after 28 days with the same metakaolin proportion.

Incorporating silica fume in the concrete mixture yielded positive outcomes for compressive and split tensile strengths. The highest compressive strength of 55.52 N/mm^2 was attained at 28 days with a 15% silica fume content. Similarly, the split tensile strength reached a maximum of 5.41 N/mm^2 at 28 days when using 15% silica fume.

Introducing basalt fibers to the metakaolin concrete mixture resulted in notable enhancements in compressive strength. Specifically, the combination of a 15% metakaolin content and basalt fibers achieved the highest compressive strength of 68.92 N/mm^2 after 28 days.

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