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BASALT FIBER REINFORCED SELF-COMPACTING CONCRETE FOR ELEVATED TEMPERATURES: A REVIEW

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ABSTRACT

In the world today, architectural design demands new materials for construction that would be durable and enhance the performance of concrete structures in different situations. There is great promise in this new material due to its self-compaction, mechanical properties, and sustainability basalt fiber-reinforced self-compacting concrete (SCC). This comprehensive study would look at basalt fiber-reinforced SCC at elevated temperatures. Many investigations have investigated temperature effects on tensile strength, and residual compressive strength, and its comparative analysis has produced complex results. The results are quite diverse as different studies have worked out their tensile strength for various temperature ranges (300℃, 600℃, 500℃, 400℃+). The tensile strength was 28% higher at 300℃, 32% higher at 600℃, and 20% lower at 500℃, 25% to 38% lower at and 400℃. In contrast, At the same ranges, the residual compressive strengths were found to be 19% higher, 70% lower, 28% lower, and 12% to 14% lower respectively. These outcomes would illustrate how various *factors interrelate to influence material behavior at different temperatures. In addition, there is no denying that this relationship among temperature, tensile strength, and residual compressive strength is influenced by the characteristics of materials, testing procedures used in each research work, and other experimental conditions that are set. To make clear conclusions regarding the effect of temperature on the tensile and residual compressive strength a deep understanding of these components is required.*

Keywords: Basalt Fiber, Self-compacting concrete (SCC), tensile strength, residual compressive strength, temperature

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1. Introduction

Over the last few years, there has been a consistent increase in the use of concrete as a building material. This might be due to increased physical infrastructure [1]. Some advantages include formability, durability, and high mechanical strength compared to many other materials. The benefits listed above are only a few of the many. Consider the following advantages that this stone-like material has in comparison to other traditional building materials. On the other hand, concrete has poor tensile strength and a limited strain capacity [2, 3]. Fiber-reinforced plastics and other non-metallic materials provide an acceptable long-range potential due to their lack of corrosion and magnetism as well as their lower modulus of elasticity compared to steel fibers [4]. Because of this, these polymers are not affected by shrinkage, anchoring, or creep losses. Due to the manufacture and usage features of fiber-reinforced polymers, they provide an alternative to typical concrete fibers that is acceptable for application.

Various fibers have been developed for use as reinforcement in concrete items such as cellulose, asbestos, polypropylene, carbon, and basalt. The basalt volcanic rocks that are the source of basalt fibers were created when these boulders crumbled into smaller pieces [5]. These fibers are very resistant to chemicals, impact, and high temperatures [6]. Sound and heat insulation systems, industrial flooring, soil reinforcement, and concrete structure rehabilitation are some potential uses for basalt fiber composites [7]. Basalt fibers are made like glass fibers; the rocks are mined, crushed, rinsed with water, and then melted at 1500 degrees Celsius [8].

The creation of fiber-reinforced composites has recently seen the emergence of basalt fiber, which is generated by melting basalt rock. Basalt fiber is a completely new material [9]. In comparison to carbon and glass fibers, basalt fibers are more cost-effective due to their efficient use of energy and the absence of any additives that are required during the manufacturing process [10]. The number of investigations that have been conducted on basalt fiber-reinforced cement composites, on the other hand, is quite low [11].

Environmentally friendly basalt fibers are advanced types of organic fibers that can be made by melting natural volcanic rocks. As opposed to the fiberglass or carbon fiber manufacturing process, it uses less energy [12, 13]. It’s cheaper than fiberglass or carbon fiber. Other aspects like thermal conductivity, microstructure, flexure, compression, lightweight concrete, geopolymer concrete, SCC, fiber-reinforced concrete, nanomaterials-infused concrete, and thermal conductivity have also been thoroughly studied concerning this material [14].

Fibrous SCC can attain high strengths without vibrations during compaction. For optimal workability and to prevent bleeding and segregation, fibrous concrete needs a low yield value and the right viscosity [15]. Besides, it keeps its uniformity throughout the installation process thus ensuring endurance of its structural parts. Multiple studies have demonstrated that the addition of fiber enhances mechanical properties to impact compressive strength in SCC [16-19]. Such concrete is usually characterized by low permeability which is important for the rehabilitation of weathered concrete which is deteriorated by the environment. The possibility of interfacial surfaces between deteriorated concrete units and newly overlay patching materials cannot be underestimated when considering the structure’s safety and operation. By virtue that harmful chemicals can easily penetrate through a weakly linked interface, there must be a strong bond and appropriate permeability between new and old concrete [20]. The latest version of fiber polymer composites has attracted significant interest from both the scientific community and the construction industry [21]. Multiple studies have demonstrated that basalt fibers significantly enhance concrete's tensile strength and reduction of brittleness. [22, 23]. Basalt has some physical properties: the basalt fibers used in Hydro Design and Management Company Pvt. Ltd. (HDM), located in New Delhi. This information is shown in Fig. 1.

Figure 1. basalt fibres [24]

The laboratory has acquired the mechanical and physical properties of basalt fiber, which are shown in TABLE 1.

Table 1. Physical properties of basalt fiber

Physical Properties	Diameter	Aspect Ratio	Specific Gravity	Melting Temperature	Tensile Strength	Elastic modulus	Elongation at break (%)	Length
Values	16±0.5	1500	2.63	1400	3200	110	3.50	24±2

Fig. 2 shows the results of the Scanning Electron Microscopy (SEM) measurements of the fibers' length and diameter. The elastic modulus, percentage of elongation at break, and tensile strength of the fiber were evaluated using a 50 kN Universal Testing Machine (UTM) [24].

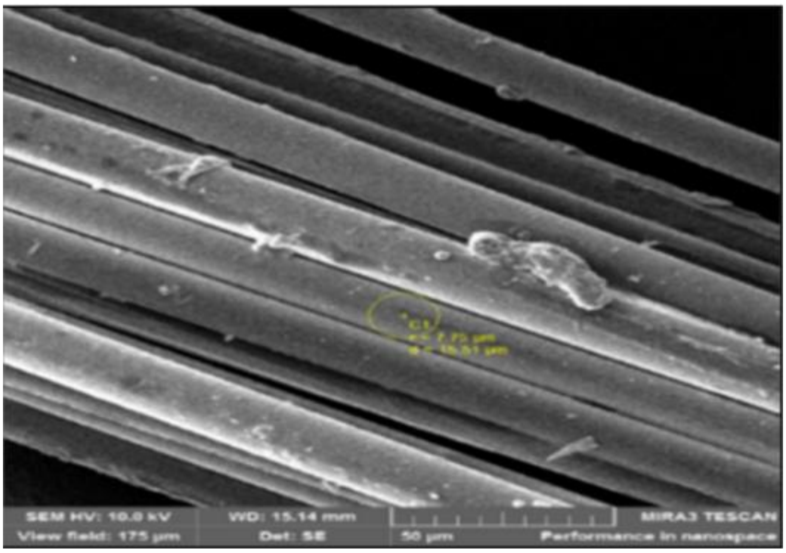

Figure 1. SEM of basalt fibers [24]

2. Related Work

In this section, several studies are analyzed based on basalt fibers and SCC.

In (2018), Aslani, and Guowei [25] investigated the effects of extreme temperatures on typical residual properties of NSLWSCC and HSLWSCC, including compressive and tensile strengths, modulus of elasticity, loss of mass, and spalling intensity, as well as on these two types of lightweight scc. The three LWA kinds used in this research are polystyrene, scoria, and perlite. Six different NSLWSCCs (50/50 perlite, 100% polystyrene, 20%, and 30% scoria) and two different HSLWSCCs (50/50 scoria) made up the mixes. As the temperature rises, the NSLWSCCs progressively lose some of their potency, reaching a maximum of 100°C. However, HSLWSCCs reached their maximum strength at 300°C. Although a significant explosion happened at 300°C in the HSLWSCC, some spalling with bubbles, holes, and cracking was seen at 900°C in the NSLWSCC still. In general, the results show that, up to a certain degree, the amount of strength loss, mass loss, and spalling severity is directly related to temperature.

In (2018), Kirthika and S. K. Singh [24] conducted a thorough investigation of basalt fiber-reinforced concrete with varying fiber percentages. Basalt fiber, when added to concrete at a dose of 0.50%, increases its compressive strength by 26.79 percent, and its splitting tensile strength by 42.71 percent compared with untreated concrete. Also, basalt fiber is hydrophilic and has an amorphous structure.

In (2019), Senthil, and P. C. Emmanuel [26] investigated SCC by conducting mechanical and durability tests to learn about the effects of basal fiber and RCA. Recycled concrete aggregate replacement percentages ranged from 0% to 100%, whereas basalt fiber concentrations were between 0.2 and 4% by volume. When compared to traditional SCC, the split tensile strength of a combination of 50 RCA and 4 kg/m3 basalt fiber was found to be 27% higher. When compared to ordinary concrete, the maximum flexural strength value for R50B2 was 22.05% higher. The strength was determined to be 42.64% lower than ordinary concrete in R100B0, with the concrete with 100% RCA substitution having the lowest strength.

In (2019), Taha, and Alaa Hasan [27] studied how fiber-reinforced concrete (FRC) affected the bond durability of helically wrapped Basalt Fiber Reinforced Polymers (HWBFRP) bars that were conditioned in a hostile salt environment. Results of the research indicate that HWBFRP bars with non-corrosive macro fibers like basalt macro fibers (BMF) added to normal-strength concrete outperformed clear concrete and steel FRC in bond strength retention after 90 days of involvement in saline solution.

In (2020), Haido et al. [28] investigated the characteristics of both new and old SCCs while taking the fiber content into account. Also presented was the topic of SCC's water and chlorite permeability. It has been shown that fresh SCC's flowability performance is unaffected by fiber content below 0.25%. As the fiber concentration increases to 1.0% in hardened SCC, its mechanical characteristics degrade by 22%. Because of the characteristics of utilized fibers and their absorption, the sorptivity of basalt fiber SCC is reduced.

In (2020), Mohammad Jani et al. [29] conducted a research investigation to determine how fiber-reinforced (FR)-SCC mechanical characteristics and heat transport were affected by a simulated hydrocarbon fire. Slabs measuring 12,000 mm square and 300 mm thick were manufactured for that purpose. The SCC was enhanced with basalt and polyvinyl alcohol (PVA) fibers at concentrations of 1, 1.5, and 2%. Results demonstrated that FR-SCC's unexposed-to-fire surface exhibited temperatures ten degrees Celsius lower than the controlled concrete, indicating that fibers provide greater insulation. The inclusion of fibers resulted in a greater decrease in strength because of softening and stiffness loss induced by high-temperature exposure, as seen by the compressive strength data. On average, basalt fibers reduced compressive strength by 30% after 120 minutes of fire exposure, whereas PVA fibers reduced it by 25%.

In (2021), Mazloom and Sajjad Lotfi [30] looked at how temperature, glass, basalt fibers (GF and BF), and self-compacting light-weight concrete (SCLC) all affected its characteristics. To achieve this goal, 12 SCLC mixtures including monotype and hybrid fibers were studied for their fresh and hardened characteristics. Slump flow, T500, V-funnel, and J-ring were used to evaluate the self-compacting characteristics of SCLC. The mechanical characteristics of SCLC were examined by conducting compressive, splitting tensile, and flexural strengths tests at ambient temperature (20 °C), as well as at high temperatures (100 and 300 °C), after 28 days of curing. All the new concrete mixes passed the SCLC test, which measures how well a material flows, how thick it is, and how easily it passes over obstacles. Fiber addition decreased compressive strength while increasing tensile, flexural, and fracture energy, according to hardened test findings.

In (2021), Xu et al. [31] enhanced the high-temperature performance of concrete by reinforcing it with basalt fiber and a high quantity of stone powder. The results showed that specimens with added basalt fiber had higher compressive strengths; however, the strength did not linearly increase with increasing fiber length or fiber content; the ideal values for both parameters were found to be 12 mm for fiber length and 1 kg/m3 for fiber content at 600°C. Although the compressive strength without restriction first rose with rising temperatures, it subsequently fell. Under conditions of 400°C, the specimens' unconfined compressive strength peaked and thereafter declined. It is shown that fiber may enhance the mechanical characteristics of concrete at high temperatures, as the strength of stone powder concrete with fiber was greater than that of the control material at 400°C and 600°C.

In (2021), Haido et al. [32] used various types of flows, and L-box height ratios to assess the impact of basalt fibers on the workability of newly mixed SCC. Under conditions ranging from 25 to 500 degrees Celsius, the hardened concrete's characteristics were studied, including its compressive and splitting strengths. Experimental results showed that both tensile strength tensional and compressive strength of SCC reduced by approximately 20% due to heating at 500 degrees Celsius.

In 2022, Mathews et al. [33] generated SCC columns mostly from SCM. Next, a thermal protective coating known as Cement Perlite Plaster (CPP) was created utilizing Ordinary Portland Cement (OPC) and the Environmental Protection Agency (EPA). For periods of 60, 90, 120, and 180 minutes, the recently created coating was put through fire testing by the ISO 834 standard fire curve. Three popular fire protection materials—GP, BW, and CW—were compared to the coating's performance. The experimental findings demonstrated that, across all exposure times, SCC specimens based on ground granulated blast furnace slag (GGBFS) were more resilient than those prepared with fly ash (FA).

In 2022, Ning et al. [34] studied the influence of different fibers on their characteristic at elevated temperatures. After natural cooling down to ambient temperature, these specimens are tested at various target temperatures ranging from 200 ◦C to 1000 ◦C. Fiber-reinforced SCC's residual compressive strength reaches a critical threshold at a temperature of 400 ◦C. Heating up through a temperature of 200 ◦C leads to a change in flexural tensile strength for SCC while curing for elevated temperatures as soon as the target temperature passes beyond the mark of 400◦C compressive strength drops significantly.

In 2022, Mostafa et al. [35] developed sustainable Ultra-High Performance Binary Fiber (UHPBF)-SCC using cement substitute through a comprehensive experimental study. Mechanically produce three dosages of nanoparticles after heat treatment at 700◦C. A study examined the reaction of UHPBF-SCC at high temperatures of 300◦C and 600◦C. Compared to the reference mix, nanoparticles increase compressive strength by over 18%, tensile strength by 32%, and flexure strength by 28%.

In (2023), Tahwia et al. [36] studied how adding chopped basalt fiber to HPC affected its workability, and impact resistance. To create sixteen different HPC mixes, Basalt Fiber was employed in three different lengths and six different volume fractions. All the mixes were tested for impact resistance and HPC compressive strength. Reinforcing HPC with 3 mm, 12 mm, or 18 mm Basalt Fiber enhanced its compressive strength by 12.2%, 15.1%, and 17.5%, respectively, compared to the control concrete. At 8 kg/m3, the impact resistance improved across the board for Basalt Fiber.

In (2023), Aghdam et al. [37] evaluated the impact that basalt fiber reinforcing had on the fracture characteristics of polymer concrete (PC) when it was subjected to a range of temperatures. In the beginning, the nanoclay reinforced PC is exposed to basalt fiber at weight percentages of 1, 2, 3, 4, and 5 percent. The incorporation of basalt fibers increases by 55.8%, 90.2%, 28.5%, and 486.6%, respectively, in KIc, KIIc, GIf, and GIIf.

In (2023), Mahmoud et al. [38] examined the impact on the microstructure, residual mechanical, and transport characteristics of several UHSFRSCC concretes of heating them to high temperatures (25 °C, 200 °C, and 300 °C) in a furnace for 1 hour. The study described an experimental investigation that was carried out systematically to evaluate the effects on fresh characteristics, mechanical properties, and sorptivity, of different combinations for example, 20% cement with 5% metakaolin and 15% silica fume, 20% cement with limestone powder, and 34% sand with quartz powder. TABLE 2 compares basalt fiber and SCC-related studies in this article.

Table 2. Comparison table

Authors and Year	Material Used	Results
Aslani, and Guowei (2018) [25]	NSLWSCC and HSLWSCC	The results show that, up to a certain degree, the amount of strength loss, mass loss, and spalling severity is directly related to temperature.
Kirthika and S. K. Singh (2018) [24]	Basalt fiber-reinforced concrete	Basalt fiber at 0.50% enhances concrete's compressive, splitting tensile, and flexural strengths by 26.79%, 42.71 percent, and 44.06%, respectively. Basalt fiber is amorphous and hydrophilic.
Senthil, and P. C. Emmanuel (2019) [26]	Basalt Fiber and RCA	The strength was determined to be 42.64% lower than ordinary concrete in R100B0, with the concrete with 100% RCA substitution having the lowest strength.
Taha, Alaa Hasan (2019) [27]	FRP and HWBFRP	Results of the research indicate that HWBFRP bars with non-corrosive macro fibers like basalt macro fibers (BMF) added to normal-strength concrete outperformed clear concrete and steel FRC in bond strength retention after 90 days of involvement in saline solution.

Haido et al. (2020) [28]	New and old SCCs	It has been shown that fresh SCC's flowability performance is unaffected by fiber content below 0.25%
Mohammad Jani et al. (2020) [29]	FR-SCC	Results demonstrated that FR-SCC's unexposed fire surface exhibited temperatures 10 degrees Celsius lower than the controlled concrete, indicating that fibers provide greater insulation.
Mazloom and Sajjad Lotfi (2021) [30]	GF, Basalt Fiber, and SCLC	Fiber addition decreased compressive strength while increasing tensile, flexural, and fracture energy, according to hardened test findings.
Xu et al. (2021) [31]	Basalt fiber and a high quantity of stone powder	It is shown that fiber may enhance the mechanical characteristics of concrete at high temperatures, as the strength of stone powder concrete with fiber was greater than that of the control material at 400°C and 600°C
Haido et al. (2021) [32]	Slump flow, J-ring flow, V-funnel flow, and L-box height ratio	The experimental findings showed that SCC's tensile and compressive strengths were almost 20% lower when heated to 500 C.
Mathews et al. (2022) [33]	SCC, SCM	The experimental findings showed that compared to the FA-SCC specimens, the SCC specimens created with GGBFS exhibited superior resilience to all exposure periods.
Ning et al. (2022) [34]	PF	The findings show that PF can successfully stop explosive spalling in the SCC. In addition, the residual compressive strength of fiber-reinforced SCC reaches a critical value at 400 ◦C.
Mostafa et al. (2022) [35]	Basalt fiber	The addition of nanoparticles results in a considerable improvement in the mechanical properties of the material, with the compressive strength increasing by more than 18%, the tensile strength increasing by 32%, and the flexure strength increasing by 28% in comparison to the reference mix.
Tahwia et al. (2023) [36]	Chopped basalt fiber to HPC	Both the compressive strength and the impact resistance are enhanced by the addition of Basalt Fiber, according to the findings.
Aghdam et al. (2023) [37]	Basalt fiber reinforcement	The results of both unreinforced and basalt fiber reinforced PCs' fracture parameters are examined concerning their exposure to temperatures of 24, 40, 60, 80, 100, 120, and 140 ◦C.
Mahmoud et al. (2023) [38]	UHSFRSCC	The findings show that flowability, viscosity, and passing ability are the rheological classes of UHSFRSCC that are unaffected by adding QP, but that MK considerably reduces them

3. Comparative Analysis

The findings of various studies, compared to the impact of temperature on tensile strength and residual compressive strength, have yielded a wide range of results showing that the interaction between these two phenomena is complicated. According to Mahmoud et al. (2023) at 300°C, experiments were carried out and they found that the tensile strength of the material increased by 28% and residual compressive strength increased by 19%. This finding indicates that there is a possibility to enhance the mechanical properties of the material through certain temperature settings. On the other hand, Mostafa et al. (2022) examined tensile strength over a higher range of temperature which was exactly 600° Celsius, and noticed a greater increase in it implying an improvement of 32% for the material but residual compressive strength showed a 70% devaluation. In contrast, Haido et al. (2021) investigated the effect that temperature had when measured at 500°C and reported a drop in tensile strength throughout this process by 20% and a 28% decrement in residual compressive strength. The inconsistency in this finding means that elevated temperatures cannot always lead to materials that are appreciably strengthened. Further, Mohammad Jani et al., (2020) further went ahead and conducted tests within a wider range of temperatures starting from about 400°C upwards wherein tensile strengths deteriorated showing losses ranging from between twenty-five and thirty-eight percent however residual compressive strength decreased from 12 to 14 %. TABLE 3 provides a summary of this comparative analysis.

Table 3. Summary of Comparative Analysis

Authors	Comparing Parameters		
	Temperature	Tensile strength	Residual compressive strength
Mahmoud et al. (2023) [38]	At 300°C	Increased by 28%	Increased by 19%
Mostafa et al. (2022) [35]	At 600°C	Increased by 32%	Lowered by 70%
Haido et al. (2021) [32]	At 500°C	Lowered by 20%	Lowered by 28%
Mohammad Jani et al. (2020) [29]	At 400°C+	Lowered by 25 to 38%	Lowered by 12 to 14%

This extensive range reflects a complex relationship with decreasing tensile strength and residual compressive strength as its outcome due to some temperature thresholds that might exist. To bridge this gap, more knowledge should be cultivated about how temperature affects tangibility regarding related information in Table 2 above. Understanding therefore must consider temperature points and ranges as well as reactions to different thermal circumstances.

4. Conclusion and Future Work

Today's contemporary construction engineering requires innovative building materials for concrete structures to last longer and be suitable for different environments. Basalt fiber-reinforced self-compacting concrete is therefore desirable because it has good mechanical properties, sustainability aspects, and self-compacting behavior. This review is therefore an extensive discussion on basalt fiber-reinforced and self-compacting concrete for elevated temperatures. A moderate conclusion is given by the comparative analysis of many studies that investigated temperature dependence of tensile strength and residual compressive strength. The results are found to be much scattered, for instance, 300℃, 600℃, 500℃ as well, and 400℃+ research was done on different temperatures to find out the tensile strength of these various temperature ranges. The tensile strength was 28% higher at 300℃, 32% higher at 600℃, and 20% lower at 500℃, 25% to 38% lower at and 400℃. In contrast, At the same ranges, the residual compressive strengths were found to be 19% higher, 70% lower, 28% lower, and 12% to 14% lower respectively. It decreases sharply at temperatures above 600 °C. These conflicting findings highlight the complex synergy of factors determining material response to different thermal conditions. The relationship between temperature and strength of residual compressive and tensile relies heavily on the specific properties of materials, experimental parameters as well as test methods used throughout every single study. Accordingly, a complete comprehension of these variables would bring accurate conclusions on how temperature affects tensile strengths and residual compressive strengths. Further research and standardization in protocols for testing may yield a better understanding of these intricate relationships in materials science.

5. Author Contribution

Conceptualization: Nikhitha Chowhan
Methodology: Nikhitha Chowhan
Investigation: Nikhitha Chowhan
Data Curation: Nikhitha Chowhan
Formal Analysis: Nikhitha Chowhan
Writing & Editing- Original Draft: Nikhitha Chowhan
Review: Dr. M. Swaroopa Rani
Supervision: Dr. M. Swaroopa Rani

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7. Competing 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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