

Research on High- Temperature Damage of Basalt Fiber Lightweight Aggregate Concrete

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Abstract

To investigate the variation laws of the mechanical properties of basalt fiber lightweight aggregate concrete (BFLAC) under high-temperature exposure, C40 lightweight aggregate concrete specimens with varying basalt fiber (BF) contents (0–0.4%) were designed. These specimens were subjected to elevated temperatures of 20, 200, 400, 600, 800, and 1000 °C, after which their residual compressive strength and residual splitting tensile strength were tested. The results indicate that the mechanical properties of all concrete groups deteriorated significantly with increasing temperature, with aggravated degradation observed above 400 °C. The incorporation of BF effectively enhanced both the compressive and tensile strengths of the concrete, with a more pronounced improvement in tensile strength; the optimal BF content was found to be between 0.2% and 0.3%. However, when the temperature exceeded 600 °C, the internal structure of the material suffered severe damage, leading to a significant reduction in the fiber reinforcement effect.

Keywords

Basalt fiber, High temperature, Residual compressive strength, Residual splitting tensile strength.

1. Introduction

Fire is one of the primary disasters causing strength degradation and microstructural deterioration in concrete structures, posing a severe threat to building durability. Fiber-reinforced concrete (FRC) serves as a critical method for enhancing the fire resistance of concrete. By bridging cracks, inhibiting crack propagation, and improving matrix integrity, FRC significantly boosts the mechanical properties and durability of concrete under high-temperature conditions.

Zhang Guangtai et al. [1] demonstrated that incorporating fibers at various volume fractions effectively enhances the mechanical performance of concrete, with particularly significant improvements in tensile strength, flexural strength, and deformation capacity. Gao Danying et al. [2] pointed out that while the mechanical properties of ordinary concrete deteriorate markedly with rising temperatures, the introduction of fibers not only improves residual compressive, flexural, and splitting tensile strengths but also effectively delays the degradation process, thereby significantly enhancing the resistance to high-temperature damage. Furthermore, experimental studies by Zhou et al. [3] on concrete with varying basalt fiber (BF) contents revealed that BF substantially improves crack resistance. Notably, the enhancement effect of BF on tensile and flexural strengths is more pronounced than on compressive strength.

Basalt fiber, characterized by excellent mechanical properties and high-temperature resistance, is a functional material with promising application prospects [4]. Incorporating BF into concrete not only improves the workability of the mixture but also effectively reduces stress concentration. Consequently, it significantly enhances the tensile and impact resistance of concrete, playing a vital role in strengthening, reinforcing, and improving structural integrity [5]. However, existing research has predominantly focused on ordinary concrete, while studies on the mechanical behavior of basalt fiber-reinforced lightweight aggregate concrete (BFLAC) under high-temperature exposure remain relatively scarce.

Therefore, this paper investigates the influence of varying basalt fiber contents on the mechanical properties of lightweight aggregate concrete through high-temperature experiments. It further explores the underlying mechanisms of high-temperature damage to provide a theoretical basis for engineering applications.

2. Experimental Overview

2.1. Raw Materials

The primary raw materials used in this study included: cementitious materials (P·O 42.5 ordinary Portland cement produced in Fushun and Class I fly ash); fine aggregate (natural river sand with a fineness modulus of 2.8); coarse aggregate (continuously graded shale ceramsite and pebbles with a particle size of 5–20 mm); admixtures (polycarboxylate-based high-performance water-reducing agent); fibers (chopped basalt fibers, with parameters listed in Table 1); and mixing water (tap water).

Table 1. Performance Parameters of Basalt Fibers

Fiber Type	Length(mm)	Diameter(μm)	Tensile Strength(MPa)	Elongation(%)
BF	12	17	2638	2.9

2.2. Experimental Scheme

2.2.1. Mix Design

Five groups of C40 concrete specimens with different mix proportions were designed for this study; the specific mix parameters are detailed in Table 2. All specimens were cast in cubic molds with an edge length of 100 mm, resulting in dimensions of 100 mm \times 100 mm \times 100 mm. To ensure the molding quality of the lightweight aggregate concrete, the shale ceramsite was pre-wetted prior to mixing to mitigate the impact of its water absorption on the workability of the fresh mixture. After casting, the specimens were compacted using standard vibration methods, left to stand at room temperature for 24 hours, and then demolded. Subsequently, the demolded specimens were cured in a standard environment at a temperature of 20 ± 3 °C and a relative humidity of not less than 95% for 28 days. This curing regime ensured sufficient cement hydration and stabilized the internal structure of the specimens. Upon reaching the specified age, the specimens were removed for subsequent high-temperature treatment and mechanical property testing to analyze the influence of varying basalt fiber contents on the mechanical performance of the lightweight aggregate concrete.

2.2.2. Experimental Method

The high-temperature tests were conducted using a muffle furnace. The target temperatures were set at 200, 400, 600, 800, and 1000 °C. The heating rate was maintained at 10 °C/min, following the protocol established in literature [6]. Upon reaching the target temperature, the specimens were held isothermally for 1 hour. Subsequently, the furnace was turned off,

allowing the specimens to cool naturally to room temperature inside the furnace before proceeding with the mechanical property tests.

Table 2. Concrete Mix Proportions (kg/m³)

Code	Water	Cement	Sand	Shale ceramicsite	Coal ash	BF	Water reducer
LC	145	320	620	768.5	60	0	5.7
LCBF _{0.1%}	145	320	620	768.5	60	0.32	5.7
LCBF _{0.2%}	145	320	620	768.5	60	0.64	5.7
LCBF _{0.3%}	145	320	620	768.5	60	0.96	5.7
LCBF _{0.4%}	145	320	620	768.5	60	1.28	5.7

3. Analysis of Experimental Results

3.1. Residual Compressive Strength

Figure 3-1 illustrates the cubic residual compressive strength of the concrete specimens. As shown in the figure, the residual compressive strength of all concrete groups exhibits a significant downward trend with increasing temperature. The overall behavior can be characterized by three stages: minimal variation between 20°C and 200°C, a marked decline after 400°C, and a sharp attenuation in the 600–1000°C range.

The incorporation of Basalt Fiber (BF) resulted in higher compressive strengths across all temperature levels compared to the plain Lightweight Concrete (LC) group. The enhancement effect was most pronounced at BF dosages of 0.2% to 0.3%, while a slight reduction was observed at 0.4%. However, as the temperature increased, the differences between the various groups gradually diminished. Particularly above 800°C, the strength values of all groups converged, indicating that severe internal structural damage at elevated temperatures progressively weakens the reinforcing effect of the fibers. Overall, these results demonstrate that BF improves compressive strength within a specific dosage range.

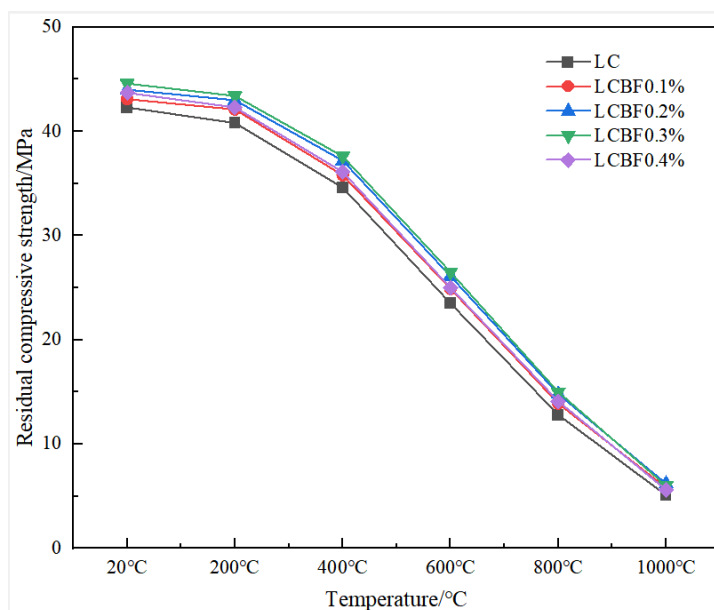


Figure 3-1. Cubic Residual Compressive Strength

3.2. Residual Splitting Tensile Strength

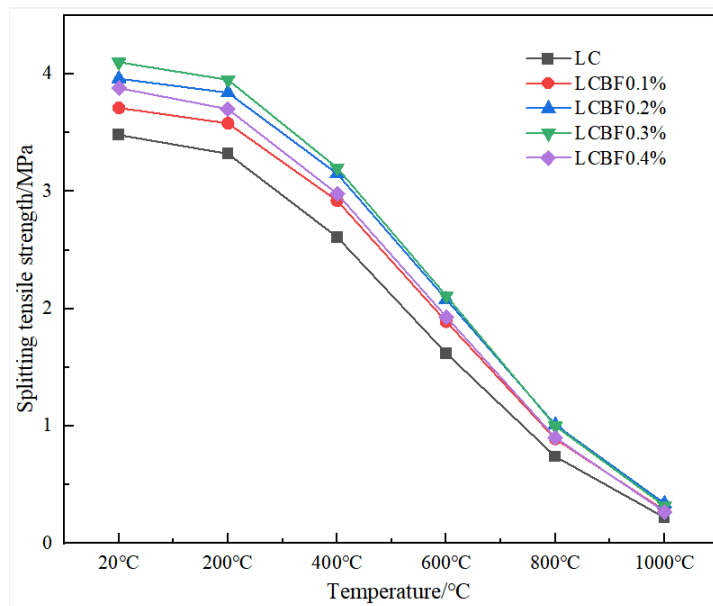


Figure 3-2. Cubic Residual Splitting Tensile Strength

Cubic residual splitting tensile strength is illustrated in Figure 3-2. As shown in the figure, the splitting tensile strength of all concrete groups exhibits a monotonic downward trend with increasing temperature, characterized by distinct stages: a slow decline between 20°C and 200°C, an accelerated drop from 200°C to 400°C, a sharp attenuation from 400°C to 800°C, and entry into a residual phase from 800°C to 1000°C where strength approaches failure.

At ambient temperature, the strength follows the order: LC < LCBF0.1% < LCBF0.4% < LCBF0.2% < LCBF0.3%. This indicates that the incorporation of Basalt Fiber (BF) significantly enhances tensile performance, with 0.2%–0.3% being the optimal dosage; the slight reduction observed at 0.4% is attributed to poorer fiber dispersion.

In the 200–400°C range, the BF groups remain significantly superior to the LC group, demonstrating that the fiber bridging effect effectively inhibits crack propagation. Beyond 400°C, strength decreases significantly, and the performance gap between groups gradually narrows. Above 600°C, severe internal structural damage occurs, weakening the reinforcing effect of the fibers. By 1000°C, the strengths of all groups converge, retaining only extremely low residual values.

4. Conclusions

- (1) The residual compressive strength and splitting tensile strength of all concrete groups decreased significantly with increasing temperature, with deterioration accelerating beyond 400°C.
- (2) The incorporation of Basalt Fiber (BF) effectively improved the mechanical properties of concrete, with a more pronounced enhancement observed in tensile strength.
- (3) An optimal BF dosage exists; the reinforcing effect was most significant at 0.2%–0.3%, whereas excessive dosage reduced the enhancement efficiency.
- (4) Within the 20–400°C range, the fiber bridging effect was substantial; however, when the temperature exceeded 600°C, the reinforcing effect gradually diminished.
- (5) At 1000°C, the concrete essentially lost its mechanical properties, retaining only extremely low residual strength.

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