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Preface

These proceedings contain the papers presented at the TENTH INTERNATIONAL CONFERENCE ON ADVANCES IN STEEL STRUCTURES (ICASS 2020) held in Chengdu, China, from 21 to 23 August 2022. The international conference series on Advances in Steel Structures was initiated in 1996 under the support of The Hong Kong Polytechnic University, which remains very active in fostering its continuation-joined a few years later by the Hong Kong Institute of Steel Construction.

These proceedings bring together most recent findings in numerical, theoretical and experimental research, as well as its practical implementation in design practice in the areas of Assembled Structure, Bridge, Cold-formed Steel, Composite, Connections, Corrosion, Fracture & Collapse, Design & Analysis, Direct Analysis, Fatigue, Fire, High-Strength Steel, Impact and Protection, Intelligent Construction, New Material, Seismic Resistance, Stability, Stainless Steel, Structure Systems, Testing & Monitoring. The papers presented in these proceedings come from a wide range of countries/regions and will be a great reference source.

Specially, the subject matter has been categorized under the broad heading of:

**Volume I:** Keynotes Lectures, Assembled Structure, Bridge, Cold-Formed, Composite, Connections, Corrosion, Fracture & Collapse, Design & Analysis, Direct Analysis, Fatigue


Each of the papers was subjected to stringent review by a panel of experts in the respective area. This peer review began with an assessment of the submitted abstracts and following this, authors were invited to submit their full manuscripts. Each manuscript was then carefully reviewed by relevant experts, and their recommendations on accepting, rejecting or modifying the submissions were strictly adhered to, before inclusion in the conference proceedings.
EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES AND OPTIMIZATION OF CHOPPED BASALT FIBER REINFORCED CONCRETE

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Abstract: This paper investigated the influence of CBF damage mode of matrix concrete and the strength of matrix concrete under different stress states. The length of basalt fiber is 6 mm. Three basic mechanical properties tests were conducted with five fiber volume admixtures of 0.00%, 0.05%, 0.10%, 0.15% and 0.20% used as the variables. A total of 90 specimens of different sizes were prepared to study the variation rules of compressive strength, splitting tensile strength and flexural strength at different ages of 7d and 28d, the strengthening mechanism of the reinforcing effect of CBF was also analyzed, and the optimal volume fraction of CBFs was obtained. The results can be concluded that (1) the disordered distribution and uniform dispersion of CBF improve the damage morphology of concrete matrix, reflecting a good effect in the enhancing and crack-resisting; (2)The compressive strength and flexural strength increase first and then decrease with increasing of the fiber incorporation amount, and the BFRC reach their strength peak points when the fiber volume ratio is equal to 0.10%; (3) The dispersion of tensile strengths are relatively high, but they still show a trend of slow increasing trend.

Keywords: Chopped basalt fiber reinforced concrete; chopped Basalt Fiber; basic mechanical properties; fiber volume; crack-resisting

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1 INTRODUCTION

Normal concrete (NC), as one of the most popular construction materials, is extensively used in civil engineering practice. However, its adverse properties of both brittle behaviour and low tensile strength are well known [1], which limits its effective use in some structures, such as the construction structures with high requirements for crack resistance, especially when these structures are also under severe environments. The steel-concrete composite structures, are the one of the common structural systems, this system have a wide range of applications in the long-span bridges, the high-rise buildings and the areas where a high seismic resistance is required. However, due to the large concentrated stress at the connector positions of the two materials, the concrete cracks occur usually around these areas, leading the durability concerns and the degradation of mechanical properties to become obviously.

Therefore, it is important to improve the deficiencies of normal concrete such as the poor crack-controlling ability, by mixing into a certain amount of reinforced materials or taking UHPC/ECC to replace it directly and so forth. The original intention of proposing fibre-reinforced concrete (FRC) is only to improve the crack resistance and durability. Additionally, the effectiveness of concrete with short steel wire (fibre) reinforcement has been validated since the 1960s -[2]. At present, it is acknowledged that the addition of steel fibres to a concrete
matrix can improve the brittle behaviour and bridge open cracks-[4], thereby enhancing the crack-controlling ability and the bearing capacity. The energy dissipation calculated by the areas of load–displacement response is much higher than those concrete structures without any fibres, while the post-peak ductility is also significantly increased [5]-[6], so that the seismic resistance performance of FRC is increased in comparison with NC. On the other hand, steel fibres exposed to chloride ion conditions are susceptible to corrosion damage [7]. This means that the steel volume expansion caused by corrosion would instead accelerate the development of concrete cracks and consequently greatly undermine the positive function of steel fibres in the concrete.

As a result, more attention has been given to other fibre types, such as carbon, basalt or synthetic fibre, as potential alternatives, of which basalt fibre, an inorganic material processed by an environmentally friendly approach, has gradually become popular in recent years [8]-[11]. This fibre has the advantages of high corrosion resistance and durability, good compatibility with cementitious materials, superior dispersion ability in mixing, cost effectiveness and the use of widespread raw resources [12]-[13]. At this point, applying basalt fibre mixed into concrete structures is deemed to be a promising project, and thus, it has become a novel direction in fibre-reinforcement research.

Relevant scholars worldwide have conducted numerous experimental and theoretical studies on the FRC material itself or the structural component composed of FRC, regardless of fibre types. The first one is for various FRC materials. The fibre inclusion in the matrix generally enables the tensile strength[14], flexural strength [15]-[17], deformation capacity [18]-[19] as well as impact behaviour [20] to show a climbing trend, whereas the compressive strength is still under debate. Many studies have considered that fibres can slightly upgrade the peak value in compression [21]-[22], as expected. In some cases, however, a reduction of varying degrees may be found in terms of the compressive strength after adding fibres [23]-[24], while scholars such as Jiang et al. [8] argued that almost no fluctuation was observed for strengthened samples in the program when compared to NC. Several studies have shown that the effects of fibre inclusions on sample strength depend on the fibre type and fibre content [25]-[27]. Moreover, it cannot be ignored that the workability of FRC is also a very important factor we need to consider in practice. Its working performance would be reduced as the volume content or the aspect ratio of fibres increases [28] As a result, the various chopped fibres, having superior workability but without any other addition, may be a better choice in the FRC field as references [29]-[31].

As mentioned above, the fibre characteristics chosen, including geometry and content, should be decided more reasonably to achieve the targeted mechanical behaviour and workability; thus, chopped fibres are suggested in some cases. Currently, little work has been carried out to explore the basic mechanical properties of basalt FRCs, especially chopped FRCs. Additionally, there is a need to clarify the strengthened effects after adding chopped basalt fibre to the concrete matrix from both the perspectives of the material properties.

Therefore, in this paper, a series of test programs (i.e., material tests and beam tests) was designed in turn, taking chopped basalt fibre-reinforced concrete (written as BFRC later) as the research object. In the material tests, ninety samples with various fibre volume fractions were completed by conducting compressive tests, split tensile tests and flexural tests to clearly characterize the BFRC material, which was followed by determining the optimal fibre volume fraction.
2 PRELIMINARY MATERIAL TESTS

2.1 Raw materials and mixtures

Normal concrete (NC) was designed according to JGJ 55-2011 [32] and cured for 28 days, and the target axial compressive strength should be greater than 20.1 MPa. The chopped fibre-reinforced concrete (BFRC) mixture is based on the NC mixture mixed with a specified fibre volume fraction. The NC and BFRC mixture are shown in Table 1. P. O 42.5 grade silicate cement was used. The coarse aggregate is made of crushed stone with a size of 5 to 20 mm, while the fine aggregate is made of river sand with a fineness modulus of 2.9. A water-to-cement ratio (w/c) of 1.82 was adopted. The fibres used chopped basalt fibres (CBFs) with a length of 6 mm, and the physical properties of the basalt fibres provided by the manufacturer are shown in Table 2. BFRC is named according to BFRC -i, depending on the fibre volume fraction incorporated. For example, BFRC 10 means that the volume fraction of fibres incorporated into the concrete is 0.10%.

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<td>850.25</td>
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<td>850.25</td>
<td>144.75</td>
<td>0.15</td>
</tr>
<tr>
<td>BFRC 20</td>
<td>264</td>
<td>507.25</td>
<td>850.25</td>
<td>144.75</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Table 2: Material properties of chopped basalt fibre

<table>
<thead>
<tr>
<th>Length (mm)</th>
<th>Diameter (μm)</th>
<th>Density (g/cm$^3$)</th>
<th>Elastic modulus (GPa)</th>
<th>Tensile strength (MPa)</th>
<th>Elongation (%)</th>
<th>$\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>15</td>
<td>2.65</td>
<td>105</td>
<td>3900</td>
<td>2.7</td>
<td>0.3–1.2</td>
</tr>
</tbody>
</table>

Note: $\gamma$ is the ratio of the chopped basalt fibre length to the coarse aggregate size.

2.2 Sample preparation and test methods

The concrete was mixed in several batches with a rotating drum-type concrete mixer with a capacity of 60 L. The mixing process is carried out as follows. a) First, the cement and sand are poured into the mixer and mixed for 1 minute, then water is slowly poured in and mixed for at least 1 minute, so that it is well mixed into a homogeneous cement mortar. b) The coarse aggregate and mix are slowly poured in over 2 minutes so that the coarse aggregate is fully encapsulated by the cement mortar. c) Finally, the weighed basalt fibres are slowly spread into the mixer by rubbing and mixing for 2 or 3 minutes so that the fibres are sufficiently dispersed in the concrete to avoid a "balling" effect.

Each group of specimens was required to cast six 100×100×300 mm prism specimens for compressive tests at 7 or 28 days; six 150 mm cube specimens were cast for split tensile tests at 7 or 28 days, and six 100×100×400 mm prism specimens were cast for flexural tests at 7 or 28 days. A total of ninety samples were cast for this series of material property tests, which can be divided into five test groups. One group was normal concrete without fibres, and the other four groups were BFRC mixed with 0.05%, 0.10%, 0.15% and 0.20% volume fractions of CBFs. The mixed NC or BFRC was poured into the moulds, and then a needle vibrating bar was used to vibrate the concrete solid, smooth the surface and demould after 24 hours. These ninety
specimens were placed under the same laboratory conditions and covered with a wet Hessian sheet for curing.

Although the 150 mm cube specimens are commonly used in compressive tests, the prismatic specimen reflects the actual compressive capacity of fibre-reinforced concrete better than the cube specimen, considering that the friction of the loading plate and prismatic specimen has less lateral constraint on the middle region of the specimen height during the loading process. The tensile strength can be obtained directly by means of a uniaxial tensile test in theory, but which is hard to conduct; therefore, splitting tests of cylinders or cubes are commonly used to get the tensile strength. The formula is shown in Equation (1), and the test configuration is shown in Figure 1. The four-point bending test is used to evaluate the flexural strength of fibre-reinforced concrete beams; on the other hand, it is also more reflective of the actual tensile strength of the bending members when the tensile area cracks. The calculation formula is shown in Equation (2), and the test equipment layout is shown in Figure 2. Compressive tests, split tensile tests and flexural tests are all conducted on a universal testing machine with a range of 200 tons, following GB/T 50081-2016[33]. The loading rate for these three strength tests is 0.5 MPa/s, 0.05 MPa/s and 0.05 MPa/s, respectively.

\[ f_{\text{ts}} = \frac{2F}{\pi d c l} \]  
(1)

Where “F” represents the peak load; \( d_c \) represents the cylinder diameter or cube side length, and \( l \) represents the cylinder length or cube side length.

\[ f_b = \frac{Fl}{bh^2} \]  
(2)

Where “F” represents the peak load; \( l \) represents the span; \( h \) represents the section height, and \( b \) represents the section width of the specimen.

2.3 Results and analysis

2.3.1 Crack patterns

The damage processes are similar for BFRCs containing different fibre volume fractions. Compared to NC, the crack pattern is improved for BFRC at the peak load; brittle behaviour became less obvious in the compressive tests, split tensile tests and the flexural tests. The typical damage morphologies of NC and BFRC in these three tests are shown in Figure 3.
In compressive tests, the damaged NC prism (see Figure 3a) has almost no crack bifurcate but has a major diagonal crack on the specimen surface, accompanied by the spalling of concrete debris, and the pressure collapse phenomenon is obvious. The BFRC (see Figure 3b) is damaged without an obvious main diagonal crack but with many secondary cracks and micro cracks that start from oblique sections and extend to both sides irregularly. Therefore, the compression failure of BFRC is not abrupt, and the crack is more moderate. The crack propagation path is no longer a main diagonal crack but fine cracks and surrounding microcracks that are more numerous, smaller in width, and more widely distributed.

It is the same for the split tensile test and flexural tests that both NC and BFRC are broken into two parts by a vertical crack. However, there is the typical difference in the crack extension path because BFRC incorporated fibres are curved and jagged, while NC is relatively flat. This is mainly due to the presence of fibres changing the crack extension path, which can only develop along with other weak interfaces. On the other hand. As reported by Patel et al.[34] and Abdulhadi et al. [35], CBFs mainly play a reinforcing role in delaying the appearance of micro cracks and making propagation more difficult before when the CBFs are pulled out or
fracture. This view is also verified by the experimental phenomenon of CBF crack resistance in this paper. Therefore, CBFs prevent crack expansion through the bridging effect, which is disordered and uniformly distributed in the concrete interior. Macroscopically, CBFs slow down the development of the crack width and length on the outer surface of the concrete, finally changing the overall crack morphology of the concrete matrix, moderating the brittle behaviour of the concrete matrix and improving the toughness.

2.3.2 Basic strength of BFRC

A comparison of the compressive strength, tensile strength and flexural strength of BFRC at 7 days and 28 days with the change in volume fraction is shown in Figure 4. The bar graph shows the average of the measured strength of each test block, and the error bar shows the standard deviation of each sample group, while the line graph shows the ratio of the strength improvement of BFRC to that of NC.

Overall, the compressive strength (see Figure 4a) and flexural strength (see Figure 4c) of BFRC showed a rising and then decreasing trend with increasing fibre volume fraction, peaking at a fibre volume fraction of 0.10%, regardless of the curing time. The same trend was found in most of the studies, such as the literature [36]-[37]. This is due to the fibre bridging effect, of which the enhancement increases with increasing fibre content in a certain range. However, when the volume fraction is greater than 0.10%, the enhancement of BFRC strength by the fibre volume fraction gradually decreases and may even lead to a negative effect, which is caused by the uneven and chaotic distribution of fibres in the concrete. When the fibre volume fraction is too high, it tends to agglomerate during the mixing process, reducing the cohesive force between the aggregate and mortar, which causes defects inside the test block and reduces the structural integrity in turn. In terms of the tensile-strength results (see Figure 4b), when the BFRC increased with the fibre content, the phenomenon of a wavy change in strength was observed. This trend is also observed in the literature [38] in tensile-strength tests. The reason for this phenomenon may be that the bridging effect of the fibre is related to the fibre orientation in the crack section and the fibre distribution being random. This means that even for the same mix, there may be different fibre distributions in each batch of casting samples, resulting in strength differences. Therefore, although the design code takes this effect into account by using three specimens as a group, an increasing number of scholars suggest that it is questionable to evaluate the tensile strength of fibre concrete simply by using three split samples in the test.
In addition, when a small amount of CBF was incorporated, especially when the fibre volume fraction was no more than 0.10%, the strength growth of fibre-reinforced concrete then increased gradually with age, with rapid growth in the early stage and slower growth in the later stage. Compared with NC at the same age, the strength of BFRC cured for 7 days increased by 22.49% and 49.07%, in compression and flexure, respectively, while that for 28 days increased by 0.13% and 29.50%. Therefore, it is more obvious for the early strength than the end-curing strength that the enhancement of chopped fibres incorporate an appropriate amount.

In summary, it can be seen that the incorporation of a small amount of CBFs, while not affecting the concrete workability and reducing the appearance of shrinkage cracks during concrete curing [39], can also effectively improve the early strength, which is beneficial to construction and structures with a requirement of concrete early hardening. It also improves the crack resistance and toughness of the members, which can help improve the durability and deformation and the energy-dissipation capacity of concrete structures. According to the analysis of the material properties of the above 90 samples, it is obvious for the BFRC matrix that the improvement of the strength and deformation capacity is best when the volume fraction of CBFs is 0.10%.

3. CONCLUSIONS

This paper successively conducted material tests with volume fractions as variables, and investigate the effect of basalt fiber on the damage mode and strength of the matrix concrete under different stress conditions. The main conclusions can be summarized as follows:

(1) Chopped basalt fibres can improve the brittle behaviour compared with normal concrete, which is attributed to the disordered distribution and uniform dispersion of chopped basalt fiber improving the damage morphology of concrete matrix and reflecting a good effect in the enhancing and crack-resisting.

(2) The compressive strength and flexural strength increase first and then decrease with increasing of the fiber incorporation amount, and the basalt fiber concrete reach their strength peak points when the fiber volume ratio is equal to 0.10%.

(3) The variation of tensile strengths with various fiber volume fraction shown a wavy trend and the dispersion of tensile strengths are relatively high, but they still show a slow increasing trend.
(4) The optimal fibre volume fraction of chopped basalt fibres is 0.10% for the improvement of the strength and enhancing of crack-resisting are most outstanding.

REFERENCES


These proceedings contain the papers at the TENTH INTERNATIONAL CONFERENCE ON ADVANCES IN STEEL STRUCTURES (ICASS 2020) held in Chengdu, China, from 21 to 23 August 2022. The international conference series on Advances in Steel Structures was initiated in 1996 under the support of The Hong Kong Polytechnic University, which remains very active in fostering its continuation - joined a few years later by the Hong Kong Institute of Steel Construction.

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