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Impact response of basalt textile reinforced concrete subjected to different velocities and temperatures

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HIGHLIGHTS

- Maximum impact force and toughness of BTRC increased with increasing impact velocity.
- Fixed boundary does increase the peak impact force as well as reduce toughness.
- The temperature and boundary should not be sensitive to the failure of BTRC specimens.
- The Weibull modulus were related to the temperature and impact velocity.

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ABSTRACT

Basalt textile reinforced concrete (BTRC) specimens were tested at different impact velocities of 0.77 m/s, 2.31 m/s and 4.62 m/s and temperatures of −25, 0, 25, 50 and 100 °C to study possible influences on their impact resistance and failure patterns. The experimental results indicate that the impact velocity, temperature, the number of basalt textile layers and boundary conditions can significantly affect the impact responses. At a constant temperature, both the maximum impact force and the energy absorption exhibit apparent increase with increasing impact velocity. On the other hand, experimental data indicate that for the same impact velocity, the maximum impact force and absorbed energy decrease with temperature at span of −25 °C to 100 °C. Both the maximum impact force and the energy absorption of the specimens are improved as the number of basalt textile layers increased from four to six. All specimens are able to absorb most of the kinetic energy under impact velocity of 4.62 m/s, since the basalt textile is mainly pulled out from the matrix. Under the impact velocity of 4.62 m/s, the fixed boundary increases the peak impact force, but reduces energy absorption compared with free boundary condition at the room temperature (25 °C). Failure patterns are significantly affected by the varying impact velocities, but not the temperature and boundary conditions.

1. Introduction

Textile reinforced concrete (TRC) or fabric reinforced cementitious matrix composite (FRCM) is a relatively new civil building material, which has a remarkable advantages during service life, such as durability, strength and ductility [1,2]. Especially, TRC composite can apparently restrain the form, propagation and distribution of micro cracks through the textile bridging effect and subsequently transform the failure pattern from a brittle failure to the multiple cracking behaviour. TRC composite materials have been a continual used since the early 1970s and gained the attention of civil engineers involved in the structural applications in recent decades [3]. Many researchers [4–10] have reported that the dynamic resistance ability of cement based materials reinforced with fibres under various conditions. Wang et al. [11] studied on the effect of different volumes of both steel fibres and propylene on impact resistance of the small beam specimen. According to Mindess et al. [12] studied on the polyolefin fibres embedded in precast concrete for improving impact resistance. Natraja et al. [13] investigated on the impact resistance of steel fiber reinforced cement composite with drop weight set-up, and the lightweight concrete reinforced with the PVA fiber was investigated on characteristics by Arisoy. B et al. [14]. Banthia et al.

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[15] investigated that the energy absorption reduced in the impact resistance at the temperature of −50 °C as compared to normal temperature. In most experimental, the cement-based composite recipes are given without fixed support condition. As the impact load is applied to an element, the element members deflect and, at any instant, there will exist any possibility forms of damage as the impact loadings goes on. It is very useful to identify the various modes of failure pattern that may happen in order to simulate the impact response correctly. Impact loading on TRC specimens result in different forms of global or localized failure, which include the spalling, scabbing and the perforation [16]. In addition, the response of cement-based materials under the impact loading is very difficult to capture at the experimental processing owing to the extreme event. From the literature [17], there are a variety of impact testing methods. Unfortunately, there is no standard technique for testing cement-based materials under impact loading [18].

Compared with plain concrete, the TRC specimens have higher capacity of energy absorption. The resistance of impact loading can be enhanced substantially due to the reinforcement of textiles in cement matrix. In most cases, cement-based materials may be suffered to low-speed impact loading in their services span [19]. Hence, studying on the response of cement-based material subjected to low-speed impact loads is very important. When the structural elements subjected to impact loads involve a complex process, structural parameters may effect impact response. The low-speed impact resistance of TRC systems is mainly based on thickness, which can be designed according to the formula that predicts the penetration and perforation limits [20,21]. In addition, higher impact rate could be accomplished even under low-speed conditions for proper selection of impact specimen dimension.

Although a lot efforts have been made on the impact loads [11–14] or temperature [15] effects on the impact behaviour of the cement based materials, but the impact resistance capacity of TRC under low-velocity was limited, and very little information can be referenced on the effect of low-speed impact in the range of 0.77–4.62 m/s, and no experimental data are available on impact response of TRC composites under different temperatures to understanding the impact responses under the extreme conditions.

The main objective of this work is to investigate the impact resistance of basalt textile reinforced concrete (BTRC) under different impact velocities and temperatures. The paper discussed the effects of different impact velocities, temperatures, number of basalt textile layers, boundary conditions on the perforation resistance of BTRC specimens. The following section discusses the temperature influence factor, which is the ratio of BTRC properties measured at other temperature to those obtained at the temperatures of 25 °C. Finally, the boundary condition and the impact failure pattern of BTRC specimens as well as intrinsic mechanisms under different impact velocities and temperatures are discussed.

2. Experimental program

2.1. Testing materials

The testing materials contain ordinary Portland cement (P·C325), standard sand with the maximum diameter of 1.2 mm. Super plasticizer was added into the cement matrix to enhance its workability. Basalt textile has a mesh size of 5 × 5 mm, as shown in Fig. 1(a), and the areal density is 168 g/m^2. In addition, tensile strength, Young's modulus and elongation of basalt textile single yarn were measured by quasi-static testing with a gage length of 25 mm. The average area of cross-sectional and perimeter of basalt warp single yarn was 0.443 mm^2 and 3.49 mm, as summarized in the Table 1. Two types of impact specimens were used in the experiments, named as BTRC-4 and BTRC-6, in which the numbers represent the basalt textile layers. The volume fractions of the basalt textile in composite are 8.6% and 15.3% for four and six layers, respectively, and volume fraction was related to a stress level referred to as the bend over point (BOP) under loading. BOP was a function of the volume fraction [22] and it was an important reference in these composites. All impact specimens were square with a dimension of 60 mm long and 15 mm thick, and the schematic of impact specimen with one layer of basalt

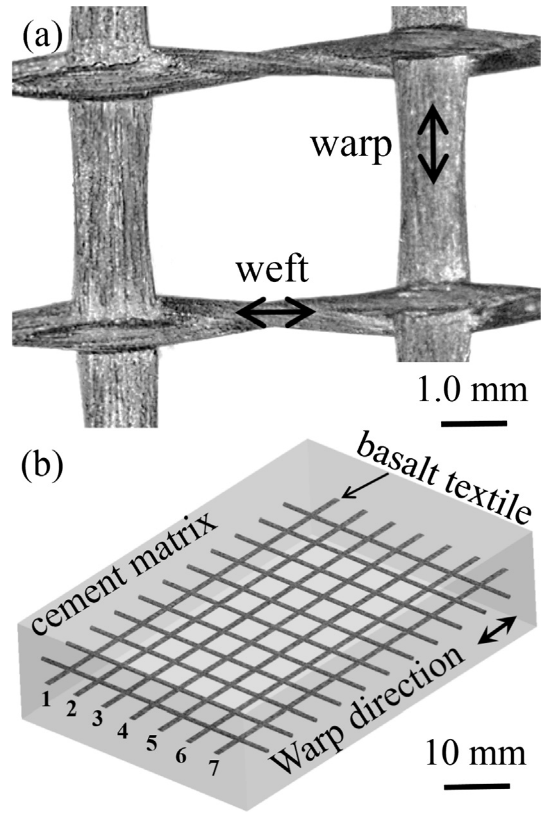

Fig. 1. Specification of materials: (a) basalt textile and (b) schematic of specimen with one layer of basalt textile embedded in cement matrix.

textile embedded in the cement matrix is shown in Fig. 1(b). Each layer of basalt textile includes six warp yarns and eleven weft yarns. Recent research has found that the mechanical properties of the TRC specimen are not only related to the radial direction of the fiber bundle, but also affected by the zonal fiber bundles [23]. Table 1 lists the mechanical and physical properties of basalt single yarn. Thousands of filaments were included in one basalt yarn with coating, so the fineness (g/m) of single yarn was quite sensitive to the number and diameter of filaments itself. The specific organization of the filaments in one yarn significantly affects the stress-strain response of this yarn [24]. If entire filaments of the single yarn were perfectly aligned and straight, the stress distribution in every filament under a given strain should be homogeneous and the finally damage of the single yarn should be the simultaneous rupture of entire filaments, thereby resulting in a better enhancement.

Table 2 shows the mix design of the cement matrix material used in all the specimens in this study. BTRC specimens were reinforced with basalt textile along direction of warping. After demolding, all the specimens were cured under standard curing conditions (20 ± 2 °C and R.H. >95%) for 28 days. Finally, all BTRC specimens were air dried under room condition before impact testing.

2.2. Testing methods

Impact experiment was conducted using a drop weight set-up, as shown in Fig. 2(a), with an anti-rebound installation in order to prevent the second impact event. Hammer drop height (*H*) of this system ranges from 0.03 m to 1.10 m with a maximum drop weight of 37.5 kg, which corresponds to a maximum impact energy of 405 J. The impact loading caused by a free fall hammer was measured through the piezoelectric load sensor with a maximum capacity of 22 kN. Impact velocity (v) from 0.77 m/s to 4.75 m/s can be achieved by adjusting the drop height (*H*). Impact velocities of 0.77 m/s, 2.31 m/s and 4.62 m/s were selected in present work which were corresponding to fall height of 30 mm, 270 mm and 1080 mm, respectively. The effect of temperatures (−25, 0, 25, 50 and 100 °C) on the impact performance were examined at each selected impact velocity. Six specimen replicates were tested for each impact velocity and temperature and the total impact weight of approximately 20.105 kg was dropped from the different free fall heights at the center position of impact specimen. The BTRC specimens were placed on the surface of the impact fixture at a designated position to make sure all test specimens in the same position during impact process. The self-contained pneumatic pressure of fixture was used for some of the specimens to achieve fixed boundary conditions while the specimens tested without pneumatic fixture were subjected to free boundary condition. The resistance to the applied force was provided by