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Mechanical behaviour of basalt fibre reinforced concrete

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HIGHLIGHTS

- Mechanical behaviour of BFRC was evaluated by flexural and impact testing.
- BFRC was made of (1) basalt bundled fibres and (2) basalt minibars.
- Both BFRC increased pre-cracking strength; had little effect under impact loading.
- Minibars significantly enhanced post-cracking behaviour but bundled fibres did not.
- Bundled fibres failed by rupturing, whereas the minibars failed by pulling out.

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ABSTRACT

Chopped basalt fibre has recently gained popularity in concrete reinforcing applications due to its environmentally friendly manufacturing process and excellent mechanical properties. The aim of this research is to evaluate the relative merit of two types of basalt fibre (bundle dispersion fibres and minibars) in enhancing the mechanical behaviour of concrete. Concrete specimens were cast with three different quantities of each fibre, then evaluated based on flexural and drop-weight impact testing. Interfacial properties were also investigated by scanning electron microscopy. The results indicated both types of fibre increased pre-cracking strength, but only minibars enhanced the post-cracking behaviour, likely due to protection from the polymer.

1. Introduction

Plain concrete (PC) is a brittle material with low tensile strength. Consequently, PC is susceptible to cracking under tensile stress. When mixed into concrete, randomly distributed fibres are able to bridge these cracks and arrest their development. By this mechanism, it has been well established that the addition of fibres can enhance the mechanical behaviour of PC. Although a variety of fibre reinforcing materials exist, fibre reinforced concrete (FRC) used for structural applications is most often made with steel fibres. The most beneficial properties of steel fibre reinforced concrete (SFRC) are improved flexural toughness, flexural fatigue endurance, and impact resistance [1]. As a result, steel fibres are able to totally or partially replace traditional steel rebar in select applications, such as industrial floors and pavements. However, SFRC poses several issues, such as: increased dead-load, reduced workability, fibre balling at high dosages, and susceptibility to corrosion. For these reasons, glass fibre is a popular alternative. Glass fibre reinforced concrete (GFRC) has been used extensively to produce thin, light-weight architectural elements, most notably exterior facade panels. The drawback of GFRC is its susceptibility to degradation in the alkaline environment of concrete, and consequently, has been largely limited to architectural applications. It should be noted FRC made with a variety of natural and synthetic fibres, including carbon, aramid, polypropylene, and wood fibres has been shown to exhibit similar enhancements to the mechanical behaviour of concrete [1], though these fibres are not currently used as commonly as steel and glass fibres in practical applications.

Basalt fibre has recently gained popularity as a potential competitor in concrete reinforcing applications due to its excellent mechanical properties and an environmentally friendly manufacturing process [2]. The fibres typically have a tensile strength slightly higher than E-glass fibres, and many times greater than steel fibres. In addition to plain chopped basalt fibres (BF), a new basalt concrete reinforcement product called minibars (MB) has recently been developed. The minibars are essentially a scaled down version of basalt fibre reinforced polymer rebar.

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The research into basalt fibre reinforced concrete (BFRC) has largely been focused on fundamental mechanical properties: compressive, split-tensile, and flexural strength. In the case of BF, the research shows general agreement with the addition of fibres being beneficial up to approximately 0.3–0.5% by volume and detrimental thereafter [3–5]. However, optimum fibre dosages vary significantly in different types of concrete, such as geopolymer [6] and high-strength concretes [7]. By comparison, MB have been shown to be beneficial at dosages up to 4% by volume [8]. The influence of BF and MB on compressive strength is typically not significant [3,5–10], although it has been shown to increase by as much as 31% with filament dispersion fibres [4]. Literature suggests the primary benefit of BF and MB in concrete under compression is the shift from a brittle failure mode to a more ductile one [5,7,8,10].

It has been shown that both BF and MB can significantly increase the tensile strength of concrete [3–9]. However, it is difficult to assess the magnitude of the increase in tensile strength because of discrepancies in values derived from direct tension, split-tensile, and flexural tests. An increase of 43% in direct tensile strength was found using BF with added zirconia, in comparison to a 14% increase without zirconia [9]. Zirconia is added to E-glass fibre to produce alkaline resistant glass fibre. This may suggest that the BF is susceptible to a similar mechanism of degradation as glass fibre in concrete. Moreover, Jiang et al. [5] found the beneficial effects of BF diminished significantly after 90 days.

Research related to characterizing the post-cracking performance of BFRC has been limited. This is a problem because in many practical applications, first-crack strength is not increased. Rather, the most significant enhancement from the addition of fibres is the post-cracking response [1]. Both BF and MB have been shown to enhance the flexural toughness of concrete [5,6,8,10]. However, it is difficult to assess the relative merit of each product since results are based on different test methods. It was found using the ACI Committee 544 recommended drop-weight test for impact resistance [11] that BF can significantly enhance performance after cracking [10]. However, the conclusion is based on data from four or six specimens per concrete mix. This test method is notorious for large variations, requiring approximately 40 specimens per mix to keep the percent error of measured mean values below 10% [12,13]. Li and Xu [14] found BF can significantly increase the energy absorption capacity of geopolymer concrete under impact loading by using a split-Hopkinson pressure bar system. However, the performance of BFRC under impact in general is not well characterized. Since impact test results obtained by different test methods are generally not comparable [15], the results from a simple test method may provide a more practical reference for which future comparisons can be made. This is particularly useful for BFRC because it is a relatively new composite and further development can be expected to enhance its material properties for concrete reinforcing applications.

The purpose of the experimental work presented in this paper is to compare the pre- and post-cracking mechanical behaviour of concrete reinforced with plain chopped basalt fibres (BF), basalt minibars (MB), and commonly used hooked end steel fibres (SF). Comparative performance is evaluated by flexural and drop-weight impact testing. Additionally, interfacial properties are investigated by scanning electron microscopy. It should be noted that two types of plain chopped BF are available: filament dispersion and bundle dispersion. Bundle dispersion fibres are manufactured with a sizing that holds bundles of basalt filaments together during mixing, whereas filament dispersion fibres will disperse into individual filaments. In this study, bundle dispersion fibres were selected since filament fibres are typically used for crack control.

2. Experimental procedure

2.1. Materials

All concrete was made with type 10 general use Portland cement conforming to the Canadian standard CSA A3001 [16], regular drinking water, and well-graded aggregates purchased locally. Superplasticizer was used in higher dosage FRC mixes.

Two different lengths of chopped BF were used: 36 mm and 50 mm. The BF bundles are flat, approximately 0.6 mm wide and made of 16 μm diameter filaments. The MB used in this study are an epoxy based resin reinforced with 17 μm diameter basalt filaments. The composite is 43 mm in length and approximately 0.65 mm in diameter. By comparison with the BF, the MB are more rigid. The SF used in this study are 38 mm in length, 0.9 mm in diameter and have hooked ends. The fibres used in this study are shown in Fig. 1.

2.2. Concrete mix design

Concrete specimens used in this study were cast with a 0.5 water-cement ratio and proportions of 1:1.4:2.8 by mass of cement, fine aggregate, and coarse aggregate. The cement was general use Portland limestone (type GUL), the coarse aggregate had a maximum size of 19 mm, and the fine aggregate had a fineness modulus of 2.7. Three different dosages were used for each type of basalt fibre reinforcement, ranging from a low dosage to the maximum mixable dosage. Despite the use of superplasticizer, it was found that dosages beyond 12 kg/m^3 and 40 kg/m^3 for BF and MB, respectively, led to fibre balling and difficulty achieving proper consolidation. A summary of the mix types used in this work is shown in Table 1. Mix designation is labelled according to fibre type, fibre length, and dosage. For example, mix designation BF-36-8 indicates chopped basalt bundle dispersion fibres of 36 mm length were used at a dosage of 8 kg per 1 m^3 of plain concrete (8 kg/m^3).


(a) BF (b) MB (c) SF

Fig. 1. Fibres used in experimental work.