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Performance of concrete beams reinforced with basalt fibre composite rebar

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HIGHLIGHTS

- Presents application of a green alternative BFRP rebar in concrete beams.
- Discusses effectiveness of BFRP-concrete beams.
- BFRP-beams exhibited acceptable deformability compared to regular beams.
- Cracking moments and V_c in BFRP-concrete beams were found to be less.
- Recommends developing BFRP bent rebar to eliminate shear failure.

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ABSTRACT

Basalt fibre reinforced polymer (BFRP) rebar is an emerging green construction material. In this research, performance of concrete beams reinforced with BFRP rebar has been evaluated. Full-scale tests on eight large-scale concrete beam specimens reinforced with either BFRP rebars or steel rebars were undertaken. The test data were analysed to evaluate the performance of BFRP rebar reinforced concrete beams in shear and flexure. It was found that at a low reinforcement ratio, BFRP rebar reinforced beams exhibited more flexural and shear cracking than counterpart steel rebar reinforced concrete beams. It was also found that BFRP reinforced beams exhibited acceptable deformability according to CSA S6-14. Cracking moments were found to be 30–50% higher for steel rebar reinforced specimens, compared to BFRP rebar reinforced specimens. The study also found that shear failure can govern the design of BFRP rebar reinforced concrete beams containing BFRP stirrups, and that V_c is 30–40% less for BFRP reinforced beams. The CSA S806-12 standard was found to be conservative in predicting V_c. However, ACI 440.1-15 standard was found to be unconservative, but in some cases accurately predicted V_c.

1. Introduction

Corrosion of steel rebar is inevitable in traditional steel-reinforced concrete structures. With the heavy use of deicing salt in cold climates, this problem is a more serious concern for durability of steel rebar reinforced concrete (RC) structures and structural elements. Hence, the use of fibre-reinforced polymer (FRP) rebar as an alternative reinforcement has been gaining popularity in addressing this issue. FRP rebars are corrosion resistant and chemically inert. Presently, there are three types of FRP rebar recommended by design standards: carbon fibre-reinforced polymer (CFRP), glass fibre-reinforced polymer (GFRP), and aramid fibre-reinforced polymer (AFRP) rebars. Each type of FRP rebar has its advantages and disadvantages in terms of its mechanical properties, durability properties, and cost. Among the three, GFRP rebar is probably the most popular choice for building and other constructions due to its relatively low cost with respect to CFRP and AFRP rebars. In recent years, various forms of products made of basalt fibres such as basalt fibre-reinforced polymer (BFRP) rebar, fabrics, meshes, and chopped fibres (Fig. 1) are made available for various civil engineering construction applications. Basalt fibres are made of volcanic rock called basalt and hence, BFRP products are a greener alternative than other FRP products.

Sim et al. (2005) [1] conducted mechanical and durability tests on basalt fibres and compared them to glass and carbon fibres. The study found that basalt fibre performed better than both glass and carbon fibres in accelerated weathering and temperature testing.

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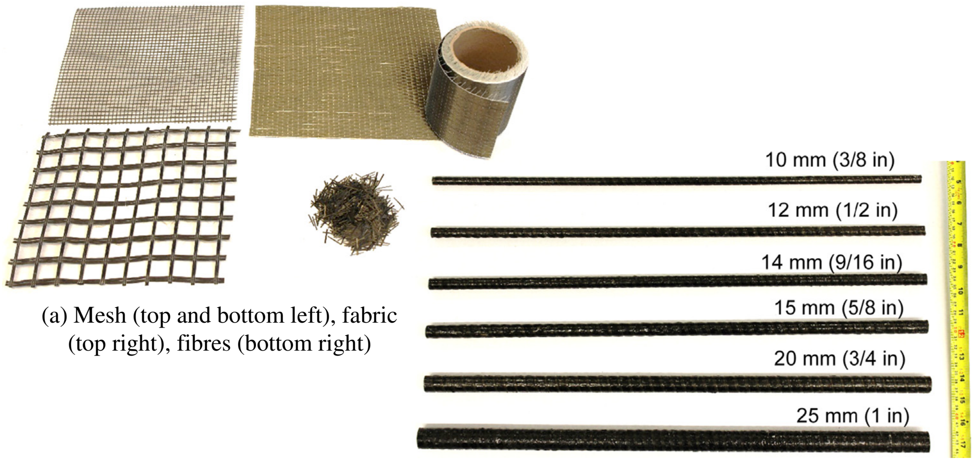

(a) Mesh (top and bottom left), fabric (top right), fibres (bottom right)

(b) Rebar in various sizes

Fig. 1. Various basalt fibre products.

BFRP rebars have been shown to have an ultimate strength of about twice that of conventional reinforcing steel rebar. Serbescu et al. (2015) [2] studied the effect of weathering on BFRP rebars and found that these rebars exhibit good strength retention in accelerated weathering conditions of heat and alkalinity. Bond durability has been shown to be excellent among BFRP rebars, and showed higher bond strength than GFRP rebar [3]. Nonetheless, all three FRPs show excellent resistance to electrochemical corrosion.

Many studies have been conducted on FRP reinforced concrete, with much of the research focused on the applications of CFRP and GFRP rebars. FRP rebar has demonstrated successful application as both flexural and shear reinforcement in various reinforced concrete structural elements including RC beams [4–7]. However, only very limited research has been conducted on the feasibility of BFRP rebar as a reinforcing material to replace traditional steel rebar. Recent studies have shown that BFRP reinforced RC beams with sufficient shear resistance can undergo a flexural mode of failure, and the failure is often initiated by crushing of concrete [8–10]. Both American standard, ACI 440.1R-15 [11] and Canadian standard, CSA 806-12 [12] specify that FRP reinforced elements should fail by crushing of concrete in flexure. Beams can be made to fail in a flexural tension manner initiated by rupture of the longitudinal BFRP bars, if the reinforcement ratio is sufficiently low [9,10]. However, when insufficient shear reinforcement is provided, BFRP reinforced concrete beams can undergo shear failure instead of flexural failure [9].

Tomlinson and Fam (2014) [9] and Issa et al. (2015) [13] found that even if bent BFRP shear reinforcement was provided, shear failure still occurred due to rupture of the BFRP bars at the bend. Thus, shear failure is still a problem that can govern the design of BFRP reinforced concrete beams. Additionally, many types of FRPs, including BFRP, are currently manufactured with thermosetting resins, and thus, cannot be reheated and bent to the desired shape, further limiting the use of BFRP as shear reinforcement [14]. Hence, Tomlinson and Fam (2014) [9] and Ovitigala et al. (2015) [8] used steel stirrups in some of their specimens to avoid shear failure and to ensure flexural failure, and thus, this did not solve the problem of shear reinforcement made of BFRP rebar.

Bentz et al. (2010) [5] studied the effect of reinforcement ratio on large GFRP reinforced concrete members. The study concluded that the behaviour is similar to that of steel reinforced concrete beams. It is a well-known, however, that bent FRP reinforcement tends to be dramatically weaker at the bend due to stress concentrations [14]. This weakness has been shown to be as high as 54% of the ultimate strength. In line with this, ACI 440.1R-15 [11] requires that FRP stirrup strength be reduced using the factor: $0.05r_b/d_b + 0.3$.

Hence, the literature review found that a few studies were undertaken to understand the behaviour of BFRP reinforced RC beams. However, none of these studies compared the behaviour of BFRP RC beam with the behaviour of steel rebar RC beams. Further, previous researches used 8 mm or lesser diameter BFRP rebars as flexural reinforcement and hence, in these studies, the scale factor was ignored. Therefore, the current study was designed carefully to eliminate scale factor induced error and to determine the behaviour of BFRP reinforced concrete beams and compare that with similar steel reinforced concrete beams. The research was completed using experimental methods.

2. Experimental procedure

2.1. Test specimens

This study consisted of eight full-scale reinforced concrete (RC) beam specimens. The beam specimens were 275 mm wide, 500 mm deep, and 3200 mm long and made with concrete that had a target strength of 35 MPa. Ready mix concrete from a local supplier was used to cast the beam specimens. Table 1 presents the different specimens tested and parameters studied. As shown in the table, the test specimens consist of steel and BFRP rebar RC beams. The test parameters studied were: two different reinforcement materials, two flexural reinforcement ratios, and the presence or absence of shear reinforcement. The naming of the beam specimens is intended to reflect their main attributes. The first letter of the name indicates if the beam specimen was made of steel rebar (S) or BFRP rebar (B). The next one is a number which represents the reinforcement ratio (0.41% and 0.83%). The last letter represents if the beam specimen had shear reinforcement (Y) or not (N). Hence, specimen S41Y is a RC beam specimen made of steel rebar (S) with reinforcement ratio of 0.41% and this beam specimen had shear reinforcement (Y).

The beam specimens in Table 1 are divided in two phases, namely I and II. Four beam specimens were built and tested in each phase. Flexural reinforcement ratios in these two phases are different. The reinforcement ratios of the Phase I and II beam specimens were 0.41% and 0.83%, respectively, producing sections having reinforcement ratios approximately equal to and twice the FRP balanced reinforcement ratio [11,12,15,16], respectively. Stirrups