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Effects of basalt and glass chopped fibers addition on fracture energy and mechanical properties of ordinary concrete: CMOD measurement

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HIGHLIGHTS

- Chopped basalt and glass fibers with 24 mm lengths were used for producing of concrete specimens.
- Four different fiber contents (0.5, 1, 2 and 3 kg/m^3) were selected for basalt and glass fiber reinforced concrete.
- Fracture energy and mechanical properties of basalt and glass fiber reinforced concrete were evaluated.
- Microstructures of the fiber reinforced concrete were investigated.

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ABSTRACT

This study investigates fracture behavior of basalt fiber reinforced concrete (BFRC) and glass fiber reinforced concrete (GFRC) comparatively. For this purpose, three-point bending tests were carried out on notched beams produced using BFRC and GFRC with 0.5, 1, 2 and 3 kg/m^3 fiber contents to determine the value of fracture energy. Fracture energies of the notched beam specimens were calculated by analyzing load versus crack mouth opining displacement (CMOD) curves by the help of RILEM proposal. In addition, microstructural analysis of the three components; cement paste, aggregate, basalt and glass fiber were performed based on the Scanning Electron Microscopy and Energy-Dispersive X-ray Spectroscopy examinations and analysis were discussed. The results showed that the effects of the fiber contents on fracture energy were very significant. The splitting tensile and flexural strength of BFRC and GFRC were improved with increasing fiber content whereas a slight drop in flexural strength was observed for high volume of fiber content. On the other hand, effect of fiber addition on the compressive strength and modulus of elasticity of the mixtures was insignificant.

1. Introduction

Concrete is a composite material with high compressive strength, low tensile strength and strain capacity. Fibers have been used to improve flexural strength, toughness, load carrying, impact, fatigue and abrasion resistance, deformation capability and ductility characteristics of concrete. In addition, fibers control the crack patterns and determine failure modes of concrete members [1–4]. There are many fibers utilized in cement and concrete materials. The most common fibers are glass, carbon, aramid, polypropylene, and basalt fibers. Fibers have remarkable structural perfection, thanks to their limited dimensions [5,6].

Basalt is a rock having high strength and durability [5,7]. Basalt fibers (BF) are made out of basalt rocks after melting procedure. Diameter range of BFs is between 13 and 20 μm. Also, BFs heat protection, thermal resistance, acoustic insulation and durability [1,5,8]. Even if BFs have aforementioned advantages, studies about BFs are limited [2,9,10]. Therefore further experimental studies should be carried out to determine effects of BF on physical and mechanical properties of composites.

Fracture energy of concrete is a substantial property used in design of concrete structures. Fictitious Crack Model (FCM) proposed by Hillerborg [11,12] is commonly used fracture mechanics model for analysis. Fracture energy (G_f) is the energy needed to develop one crack completely. RILEM [13] and Peterson [14] recommended a method for calculation of G_f using three-point bending test on notched beams.

One of the major roles of fibers in concrete is to increase the fracture energy [15–17]. Even if many fiber types have been used in concrete [15,17–19], knowledge related to mechanical properties, fracture behavior and microstructure of basalt fiber reinforced concrete (BFRC) is insufficient. Therefore, the main objectives of

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this study are to determine mechanical properties, fracture behavior and to investigate microstructure of BFRC and glass fiber reinforced concrete (GFRC), comparatively. To determine the value of fracture energy, three-point bending tests were performed on notched beams produced using GFRC and BFRC with 24 mm fiber length and 0.5, 1, 2 and 3 kg/m^3 fiber contents.

2. Experimental study

2.1. Materials and specimen preparation

In this study, CEM I 42.5R Portland cement was used for producing of BFRC and GFRC specimens. The mixture proportions of the concretes are shown in Table 1. The W/C ratio was kept constant as 0.50 for all mixtures. Also, 1.0% high-range water reducing admixture was used by weight of cement for concrete mixtures to achieve proper workability.

In order to determine the fracture energies of Ref, BFRC and GFRCs, 27 notched beams were tested by three point bending test. The dimensions of all specimens are 50 × 100 × 480 mm with a notch height to beam height ratio (a_0/d) equal to 0.3 and a free span to beam height ratio (S/d) equal to 4 in accordance with RILEM [13]. Details of the notched beam specimen are given in Fig. 1.

As it was mentioned above, BFs and GFs with 24 mm fiber length and four different (0.5, 1, 2 and 3 kg/m^3) fiber contents were used to reveal effects on mechanical and fractural behavior of BFRCs and GFRCs. Detailed properties provided by manufacturer and BFs and GFs are presented in Table 2 and Fig. 2 [5,6]. Modular steel molds having a plate in the middle to form notches have been used for producing of the notched beam specimens (Fig. 3).

2.2. Methods

Compressive strength tests have been carried out on three 150 mm × 300 mm cylinder specimens and averages of the test results of each series were obtained. Splitting tensile strengths of 150 mm cube specimens were calculated using the following expression:

$$f_{st} = 2P/\pi a^2 \quad (1)$$

where P and a are the ultimate load and edge dimensions of the specimen, respectively. Test specimens were loaded linearly as displacement controlled using Universal Test Machine (Fig. 4). Time versus Crack Mouth Opening Displacement (CMOD) relation is given in Fig. 5. As seen in the figure displacement controlled loading is almost linear. Loading speed of the three-point bending test was determined as 0.009 mm/min (Fig. 5). For all the specimens end of test were determined as 95% drop in peak load.

CMOD was measured using a clip gauge located in mid-span of the beam by the help of steel knife edges. A video-extensometer was used to measure the deflection of the middle span. Fracture energy (G_f) was calculated by the help of the RILEM [13] proposal given in Eq. (2).

$$G_f = \frac{W_0 + mg\delta}{A} \quad (2)$$

where W_0 is the area under the load-CMOD curve (N/m), mg is the self-weight of the specimen between supports (kg), δ is the maximum displacement (m), and A is the fracture area [b(d − a_0)] (m^2); b and d are the width and height of the beam, respectively. Flexural strength of concretes was calculated using three-point bending test results with Eq. (3).

$$f = \frac{3PS}{2b(d - a_0)^2} \quad (3)$$

where P is the maximum load, S is the span length, b is width of the specimen, d is height of the specimen, and a_0 is notch depth. Modulus of elasticity (E) of the BFRC and GFRC are calculated from the measured initial compliance C_i of load-CMOD curve using Eq. (4) [20–23].

$$E = \frac{6Sa_0V_1(\alpha)}{(C_ibd^2)} \quad (4)$$

where $V_1(\alpha)$ is a function (Eq. (5)) dependent on ($\alpha = (a_0 + h_0)/(d + h_0)$) and h_0 thickness of steel knife edge,

$$V_1(\alpha) = 0.76 - 2.38\alpha + 3.87\alpha^2 - 2.04\alpha^3 + 0.66/(1 - \alpha)^2 \quad (5)$$

Table 1
Mixture proportion of the concretes.

Concrete code	Fiber Content (kg/m^3)	Cement (kg/m^3)	W/C ratio	Coarse aggregate (5-12 mm) (kg/m^3)	Fine aggregate (0–5 mm) (kg/m^3)	Super plasticizer (kg/m^3)
Ref	–	350	0.5	740	1100	3.5
BFRC-24-0.5	0.5					
BFRC-24-1	1					
BFRC-24-2	2					
BFRC-24-3	3					
GFRC-24-0.5	0.5					
GFRC-24-1	1					
GFRC-24-2	2					
GFRC-24-3	3					

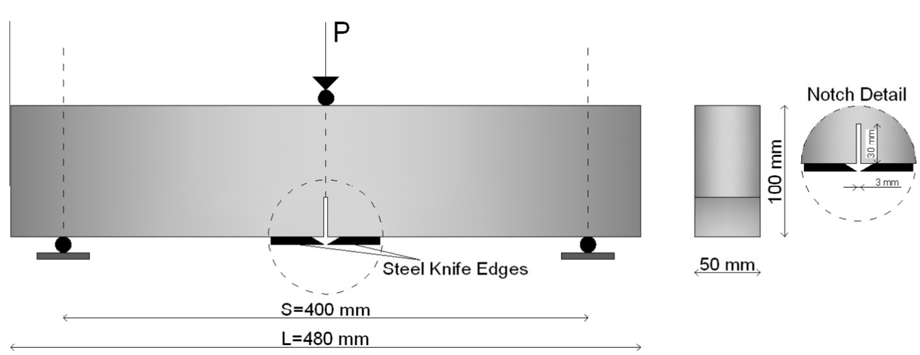

Fig. 1. Dimensions and details of notched beam test specimens.

Table 2
Properties of basalt and glass fiber.

Fiber type	Fiber length (mm)	Diameter (μm)	Modulus of elasticity (GPa)	Elongation (%)	Tensile strength (MPa)	Density (g/cm^3)
Basalt	24	13–20	88	3.15	4000–4500	2.80
Glass	24	10–17	76	2.65	3000–3600	2.60