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Mechanical properties and fracture behavior of basalt and glass fiber reinforced concrete: An experimental study

Ahmet B. Kizilkanat [a,*], Nihat Kabay [a], Veysel Akyüncü [b], Swaptik Chowdhury [c], Abdullah H. Akça [d]

[a] Department of Civil Engineering, Yildiz Technical University, Istanbul, Turkey
[b] Department of Civil Engineering, Namik Kemal University, Tekirdag, Turkey
[c] School of Sustainable Engineering and Built Environment, Arizona State University, AZ, United States
[d] Department of Civil Engineering, Bogazici University, Istanbul, Turkey

HIGHLIGHTS

- The mechanical and fracture properties of BFRC and GFRC are compared.
- Insignificant increase in compressive strength in BFRC and GFRC.
- Flexural strength higher in BFRC than GFRC.
- Fracture energy improved with higher fiber dosage.
- Better performance of BFRC in crack resistance and ductility than GFRC.

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ABSTRACT

Basalt fiber (BF) is a novel kind of inorganic fiber which is manufactured from the extrusion of melted basalt rock and is commercially available. This study comparatively analyze the application of basalt and glass fibers as fiber reinforcement in high strength concrete. It was observed from the test results that there was no significant effect of fiber inclusion on the compressive strength and modulus of elasticity of concrete. The splitting tensile strength of basalt fiber reinforced concrete (BFRC) increased with increasing fiber dosage whereas there was no increase in strength for glass fiber reinforced concrete (GFRC) was observed beyond 0.50% fiber dosage. In a trend similar to splitting tensile strength, the flexural strength of BFRC increased with increasing fiber content in a gradual fashion but no such change was observed for GFRC after 0.50% fiber content. Fracture energy increased significantly after 0.25% dosage for both basalt and glass reinforced concrete. The K_{IC} and $CTOD_C$ results of the BFRC showed that BF inclusion improves the performance of concrete more when compared to GF with respect to crack resistance and ductility.

1. Introduction

Concrete is one of the most conventionally consumed construction materials. Concrete has several advantages such as durability, formability and desired mechanical strength which gives it an edge over the other conventional building materials but it has few disadvantages such as low tensile strength and strain capacity [1–3]. Concrete technology had undergone a major evolution in the last 4 decades and it is virtually possible to manufacture job application oriented concrete mixes with normal construction material. High strength concrete and ultra-high strength concrete are some examples of such tailored concrete which exhibit extremely higher strength at early ages but also exhibit unusual brittleness. Usually fibers are included in the cement matrix to improve the mechanical and fracture properties and several researchers have investigated the effects of fiber inclusion in cement matrix depending on the fiber content and type [4–7].

Fiber inclusion in matrix greatly influences the properties of concrete and various studies have shown that the fibers can significantly improve the engineering properties of the concrete such as the tensile strength, flexural strength, impact, fatigue and abrasion resistance, deformation capability, toughness and load bearing capacity after cracking [3,8]. However the effect of fiber inclusion on the compressive strength of concrete is still under debate as some researchers observed an increase in the compressive strength

* Corresponding author.
E-mail address: bkkanat@yildiz.edu.tr (A.B. Kizilkanat).

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with fiber inclusion whereas some reported a decrease in the compressive strength [9–15]. Some researchers [16,17] even concluded that the fiber inclusion have insignificant effect on the compressive strength.

Different types of fibers such as asbestos, cellulose, steel, polypropylene, PVA, carbon, basalt, aramid, polyethylene and glass have been used to reinforce cement products [18]. Basalt fiber (BF), is a new kind of inorganic fiber made by the extrusion of melted basalt rock and is available in the commercial market. The BF does not contain any other additives, which makes it more economical. It is known that the BF has better tensile strength than the E-glass fiber, greater failure strain than the carbon fiber as well as good resistance to chemical attack, impact load and fire with less poisonous fumes. So, BF has a potential to be a suitable replacement for glass, steel and carbon fibers in many construction applications [19,20]. Previous studies showed that the effect of BF addition significantly improved the tensile strength, reduced the brittleness, and improved the toughness, deformation resistance and modulus of rupture of concrete [12,21–23]. Research conducted by Jin et al. [24] showed that the performance of dynamic modulus of elasticity and quality loss of BF concrete in freezing and thawing process is obviously better than the plain concrete.

Chandramouli et al. [25] conducted studies on GFRC and reported 20–25% increase in compressive strength and 15–20% increase in flexural and splitting tensile strength. Similar trend was observed by Tassew and Lubell [26] where the flexural strength of ceramic concrete increased with increase in the glass fiber (GF) volume fraction irrespective of the mix composition or fiber length. The compression toughness index, flexural toughness and shear toughness of ceramic concrete showed a considerable increase with an increase in the fiber content which was true regardless of the type of matrix or fiber length [26].

Although several types of fibers have been used in concrete, however there is only limited information available on mechanical properties and fracture behavior of high strength concrete incorporating BF which is of great importance in understanding the material behavior and in designing structures. The primary aim of this paper is to study, analyze and compare the mechanical properties and fracture behaviors of concretes reinforced with basalt and glass fiber and present a comprehensive study highlighting the properties of reinforced concrete in a comparative perspective. The reason for the selection of GF to compare with BF is their similar engineering properties.

2. Experimental study

2.1. Materials and mixture proportions

The mix proportion of concrete prepared for this study is presented in Table 1. The water to binder ratio of the concretes is kept constant at 0.45 for all mixes. To obtain a desired level of workability in the concrete, polycarboxylate based superplasticizer (SP) was used at varying dosages. CEM I 42.5 R Portland cement and fly ash (10% replaced with cement by weight) were used as cementitious materials. The physical and chemical properties of cement and fly ash are listed in Table 2. The aggregates used in this study are limestone coarse aggregate with a particle density of 2.77 kg/dm^3, natural river sand with a particle density of 2.75 kg/dm^3 and crushed limestone sand with a particle density of 2.65 kg/dm^3. Maximum particle size of the coarse aggregate, natural river sand and crushed limestone sand is 11.2 mm, 2 mm and 4 mm respectively. Four different volume fractions (0.25%, 0.50%, 0.75%, and 1%) of BF and GF respectively, were adopted to study their effect on the properties of concrete. Detailed properties and the pictures of the basalt and glass fibers used in this study are presented in Table 3 and Fig. 1 respectively. After casting, the samples were cured at room temperature for 24 h. After demolding, all samples were kept in lime saturated water till testing day.

The nomenclature adopted was: R representing the plain concrete; BF and GF representing the basalt and glass fiber reinforced concrete, respectively and the numbers written after BF or GF letters indicating the percentage of fiber added in the concrete.

Table 2
Properties of cement and fly ash.

Composition (%)		CEM I 42.5 R	Fly ash
CaO		62.98	1.17
SiO_2		20.54	53.26
Al_2O_3		5.12	19.54
Fe_2O_3		3.26	6.25
MgO		1.14	4.56
SO_3		3.04	2.12
Na_2O/K_2O		0.26/0.78	–
Cl^-		0.0395	
Loss of ignition		1.32	7.56
Insoluble residue		0.47	–
Specific gravity		3.14	2.65
Specific surface (cm^2/g)		3640	4900
Setting time (min)	Initial	101	–
	Final	158	–
Soundness (mm)		1	–
Strength (Mpa)	2 days	27.4	–
	7 days	39.4	–
	28 days	54.0	–

2.2. Test setup and procedure

2.2.1. Compression test

Compressive strength test according to EN 12390-3 [27], was performed on cube specimens with dimensions of 150 mm. Three specimens were tested for each mixture and average was reported in this paper.

2.2.2. Determination of modulus of elasticity

Cylindrical specimens with dimensions of 100/200 mm were used for determining the static modulus of elasticity in accordance with ASTM C469M [28] using the stress–strain response, as given by Eq. (1).

$$E = \frac{(S_2 - S_1)}{(\varepsilon_2 - 0.00005)} \quad (1)$$

Table 1
Mix proportions and fresh properties of concrete mixtures.

Concrete mixtures	Cement (kg/m^3)	Fly ash (kg/m^3)	Water (kg/m^3)	Coarse aggregate (kg/m^3)	Crushed sand (kg/m^3)	River sand (kg/m^3)	Fiber content		SP (kg/m^3)	Slump (cm)	Fresh density (kg/m^3)
							By weight (kg/m^3)	By volume (%)			
R	360	40	180	931	509	436	0	0	3.2	18	2444
BF0.25	360	40	180	931	509	436	6.75	0.25	3.6	11	2424
BF0.50	360	40	180	931	509	436	13.50	0.50	5.2	13	2404
BF0.75	360	40	180	931	509	436	20.25	0.75	6.4	13	2404
BF1.00	360	40	180	931	509	436	27.00	1.00	7.6	14	2429
GF0.25	360	40	180	931	509	436	6.50	0.25	4.0	12	2424
GF0.50	360	40	180	931	509	436	13.00	0.50	4.8	8	2381
GF0.75	360	40	180	931	509	436	19.50	0.75	6.8	11	2409
GF1.00	360	40	180	931	509	436	26.00	1.00	8.0	8	2409