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# Use of basalt fibers for concrete structures

Cory High [a], Hatem M. Seliem [b,*], Adel El-Safty [c], Sami H. Rizkalla [a]

[a] Department of Civil, Construction and Environmental Engineering, NCSU, Raleigh, NC, USA
[b] Department of Civil Engineering, Faculty of Engineering, Helwan University, Cairo, Egypt
[c] School of Engineering, University of North Florida, Jacksonville, FL, USA

## HIGHLIGHTS

- BFRP bars had an $f_{fu}$ = 1,000 MPa, $E_f$ = 45 GPa, and $L_d = 32d_b$.
- Flexural members with BFRP bars are controlled by serviceability requirements.
- ACI 440.1R-06 accurately predicts the nominal moment capacity.
- ACI 440.1R-06 underestimates service deflection for low reinforcement ratios.
- Basalt fibers increased $f'_c$ & $f_r$ of concrete containing fly ash with low w/c.

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## ABSTRACT

This study investigated the use of basalt fiber bars as flexural reinforcement for concrete members and the use of chopped basalt fibers as an additive to enhance the mechanical properties of concrete. The material characteristics and development length of two commercially-available basalt fiber bars were evaluated. Test results indicate that flexural design of concrete members reinforced with basalt fiber bars should ensure compression failure and satisfying the serviceability requirements. ACI 440.1R-06 accurately predicts the flexural capacity of members reinforced with basalt bars, but it significantly underestimates the deflection at service load level. Use of chopped basalt fibers had little effect on the concrete compressive strength; however, significantly enhanced its flexural modulus.



### 1. Introduction

Basalt fibers are produced from basalt rocks, which are melted at 1400 °C. Basalt fibers are environmentally safe, non-toxic, and possess high stability and insulating characteristics [1]. Basalt Fiber Reinforced Polymer (BFRP) reinforcing bars have been recently introduced as an alternative to steel reinforcement for concrete structures and as external reinforcement for retrofitting of concrete structures. Unlike Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) materials, basalt fibers have not been widely used. The limitation of their use may be attributed to the lack of fundamental research and extensive testing required to establish appropriate design recommendations and guidelines. Chopped basalt fibers have been also introduced as an additive to concrete mixes to produce fiber reinforced concrete (FRC).

The research presented in this paper comprises two main studies. The first study evaluated the behavior of flexural concrete members reinforced with BFRP bars. The study included assessments of the mechanical properties and the bond strength of two selected BFRP bars having two different surface deformations. The first BFRP bars were ribbed and the second were dented. The second study investigated the use of chopped basalt fibers as an additive to concrete mix to enhance the mechanical properties of hardened concrete. Two different short basalt fiber products were investigated in the second study.

* Corresponding author.
*E-mail address:* hmseliem@gmail.com (H.M. Seliem).

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## First study: flexural behavior of concrete members reinforced with BFRP bars

## 2. Background

Ramakrishnan et al. [1] investigated the use of basalt fiber bars for reinforcing concrete members. Test results indicated that specimens reinforced with BFRP bars with short bond lengths exhibited gradual slip prior to failure. Specimens with long bond lengths exhibited sudden failures due to rupture of the BFRP bars. Patnaik [2] studied the flexural strength of 13 concrete beams reinforced with BFRP bars and compared the measured failure loads to those predicted by ACI 440.1R-06 guidelines. The study concluded that prediction of moment capacities by ACI 440.1R-06 agrees well with the measured values. Ovitigala [3] investigated the behavior of lightweight and normal weight concrete beams reinforced with BFRP bars. The study reported that ACI 440.1R-06 [4] predicted 77–93 percent of the measured moment capacities. In addition, the study reported higher deflections for BFRP-reinforced concrete beams in comparison to steel-reinforced concrete beams with the same flexural capacity.

## 3. Mechanical properties of BFRP bars

A total of ten coupons, five coupons for each of the ribbed and dented bars, were tested in tension according to ASTM D7205 [5]. The tension coupons had a 305 mm gripping length at each end and a free length of 610 mm. The gripping length consisted of epoxy-filled steel pipes attached to each end of the test coupon. The elongation of the tension coupons was measured using a 50 mm extensometer. The average engineering stress–strain relationships of the ribbed and dented BFRP bars are shown in Fig. 1. The average measured cross-sectional area of the ribbed and dented BFRP bars is 109 mm$^2$. The equivalent nominal diameter of both bars is approximately 12 mm. The measured cross-sectional area and equivalent diameter of the bars were determined by volume water displacement according to ACI 440.3R-04 [6]. It should be noted that the ribs were excluded from the measured area.

The tension coupons exhibited a linear stress–strain relationship up to rupture of the bars. The average measured moduli of elasticity of the ribbed and dented BFRP bars were approximately 48.3 GPa and 41.4 GPa, respectively. Therefore an average value of 45 GPa can be used for the modulus of elasticity. The average measured ultimate tensile strength for both bars was approximately 1000 MPa. The average measured rupture strains of the ribbed and dented bars were 2.2% and 2.5%, respectively.

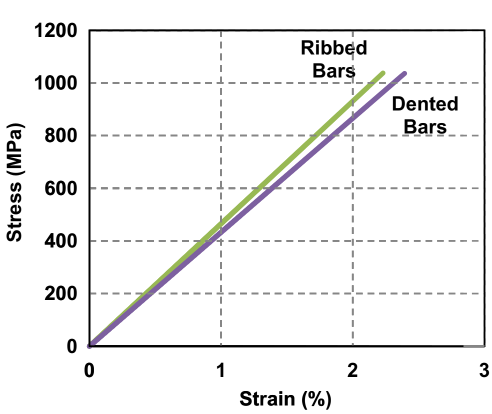


**Fig. 1.** Typical stress–strain relationship of BFRP bars.

## 4. Bond strength of BFRP bars

### 4.1. Test specimens and test setup

Beam-end specimens were tested to assess the bond characteristics of the two types of BFRP bars with different surface deformations (ribbed or dented). A total of eight specimens, four specimens for each bar type, were tested. The development length according to the equation provided by ACI 440.1R-06 [4] for GFRP and CFRP bars was 762 mm, which is approximately equivalent to 65 times the bars diameter. Accordingly, four different bond lengths were selected for this study, 380 mm, 610 mm, 1015 mm, and 1270 mm, which are equivalent to 32, 51, 85, and 106 times the bar diameter, respectively. It should be noted that the four selected test bond lengths were longer than and shorter than that estimated using ACI 440.1R-06.

The concrete beam-end specimens had a total length of 1524 mm to accommodate the longest bond length. The depth of the specimens was 610 mm to eliminate the influence of the compressed concrete zone on the bonded length of the bar. A width of 305 mm was used to provide enough bearing strength. The specimens were cast with the BFRP at the bottom position and the specimens were rotated prior to testing. Details of specimens are shown in Fig. 2.

All tested bars were 2134 mm long to provide an embedment length of 1524 mm within the specimen and an overhang length of 610 mm to grip the bar. A PVC pipe was used at the unloaded end to break the bond and to provide the specified bond length. A 102 mm PVC pipe was used at the loaded end to avoid possible localized failure of the concrete.

Two linear potentiometers were attached to the loaded end of the test bar to measure the elongation of the bar. Similarly, two linear potentiometers were attached to the unloaded end (free end) of the BFRP bar tested to measure the slip of the bar. Elongation of the test bars was measured using a 50 mm extensometer located within the free length of the bars. The test setup is shown in Fig. 3.

### 4.2. Test results and discussion

Test results of the ribbed bars "R" and the dented bars "D" are given in Table 1 including the observed failure mode (see Fig. 4), the maximum measured stress in the bar at failure, and the measured concrete compressive strength at the day of testing. Test results indicate that the ribbed and dented BFRP bars have similar bond strengths. A bonded length of 380 mm, which is equivalent to 32 times the bar diameter, was found to be sufficient to develop the full strength of the BFRP bars used in this study.

## 5. Flexural behavior of BFRP-reinforced members

### 5.1. Test specimens

Six one-way slabs reinforced with ribbed BFRP bars only were tested in flexure up to failure. The specimens were 3658 mm long

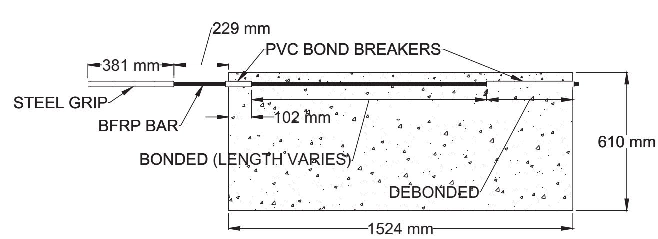


**Fig. 2.** Details of beam-end specimens.