Evaluation of Mechanical Characteristics of Basalt FRP Bars

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Abstract— Fiber-reinforced polymer (FRP) is a vital replacement to the traditional steel reinforcement for concrete structures. However, the newly developed basalt FRP bars offering superior physical and mechanical properties compared to the commonly used FRPs; such as glass and carbon FRP bars. Therefore, basalt FRP became an interesting material for researchers to be investigated and utilized in the construction sector. This paper experimentally studies the mechanical characteristics of newly produced basalt FRP reinforcing bars. The basalt FRP bars used are 12 mm diameter with helical ribs. Mechanical properties such as tensile properties, flexural strength, transverse shear strength, interlaminar shear strength, and bond strength were investigated. The test results confirmed that the basalt FRP bars have the potential to be a competitor to the glass FRP through satisfying the requirements of the specification for fibre-reinforced polymers such as CSA S807 (2010), ASTM 7957 (2017), and ACI 440.6M (2005).

INDEX TERMS— Basalt, FRP, Tensile, Shear, Bond.

1. INTRODUCTION

The steel reinforcement is the most commonly used material for reinforcing the concrete structures. However, the durability of steel in reinforced concrete structures is harshly degraded due to the external environments such as de-freezing salt and chlorides. Therefore, a lot of researchers made efforts to get a durable remedy for this problem. Fiber-reinforced polymers (FRP) provide a promising solution for the degradation of the steel bars [1,2]. Several studies investigated the physical and mechanical properties to provide the knowledge required about basalt FRP (BFRP) [3–5]. However, till now the design codes and specifications do not cover the basalt fibers due to the lack of knowledge about this material. This means more researches are required to get knowledge about the BFRP. Seis et al. [6] made a comparative study between BFRP bars and ordinary steel reinforcement (OSR) bars, BFRP bars offered higher bond strength compared to OSR bars. The need for understanding the performance of BFRP bars may be a significant obstacle to accept them in the field applications.

This paper presents an experimental investigation that aims to characterize the mechanical properties of BFRP bars such as tensile strength, interlaminar shear strength, transverse shear strength, and bond strength. The conclusions of this work shall contribute to include BFRP bars into FRP codes and specifications.

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2. EXPERIMENTAL PROGRAM

A comprehensive research project is being conducted at Ain Shams University to characterize and evaluate the short and long-term performance of BFRP bars. The main objective of this research project is to get a well-established knowledge base about the mechanical properties of the new basalt FRP bars as preliminary steps to get the confidence about this material to be included in the design guides and specifications.

The tests performed to assess the mechanical properties of the BFRP bar are the following: tensile properties determined according to ASTM D7205-06 (2016) [7], flexural strength according to ASTM D4476-14 [8], interlaminar shear strength according to ASTM D4475-02 (2016) [9], transverse shear strength according to ASTM D7617-11 (2017) [10], and bond strength according to ASTM D7913-14 [11], and ACI 440.3R-12 [12].

2.1 Properties of BFRP Bars

The BFRP bars used in this study have a nominal diameter of 12 mm, with spiral ribs on a deformed surface with distinct winding filaments on the surface Figure 1.

Figure 1: Surface Configuration of the BFRP Bars

2.2 Concrete Mix

Pull-out specimens were made to investigate the bond strength. The pull-out specimens were made of normal strength concrete with a target compressive strength of 30 MPa. The cubic meter of the concrete mix contained 350 kg of cement 42.5N, 745 kg of natural medium-size sand, 1117 kg of crushed stones of 10 mm nominal maximum size, and 56% of a water/cement ratio. The cubic compressive strength was determined by testing concrete cubes of 100 mm on the day of specimen testing.

3. TEST MATRIX, RESULTS, AND DISCUSSION

3.1 Tensile Properties

The tensile properties of the BFRP bars were determined by testing five specimens according to ASTM D7205-06 (2016) [7]. The tensile strength, modulus of elasticity, and the ultimate strain at failure of the tested specimens are listed in Table 1. Figure 2 shows the test setup and Figure 3 shows the typical failure mode of BFRP bars in tension.

Table 1: Mechanical Properties of BFRP Bars

Property	Test Result	Specified Limits for GFRP	
		ACI 440.6M-5 [13]	CSA S807-10 [14]
Diameter* (mm)	11.70 ± 0.08	13	13
Ultimate Tensile Strength (MPa)	1021 ± 24	690	650
Elongation at Break (%)	2.27 ± 0.14	1.2%	1.2%
Modulus of Elasticity (GPa)	45.0 ± 2.2	39.3	40.0
Flexural Strength (MPa)	727 ± 22	N/A	N/A
Transverse Shear Strength (MPa)	160 ± 9	124	160
Interlaminar Shear Strength (MPa)	59.55 ± 2.57	N/A	N/A
Bond Strength (MPa)	25.32 ± 1.52	9.6	8.0

*The actual bar diameter was determined according to ASTM D7205-06 (2016) [7], and ACI 440.3R-12 [12].

Figure 2: Tensile Test Setup of BFRP Bars

Figure 3: Typical Failure Mode of BFRP Bars in Tension

The tested BFRP bars showed a linear elastic tensile stress-strain relationship up to failure, similar to all FRP products. The tested BFRP bars showed high tensile strength and modulus of 1021± 24 MPa and 45.0± 2.20 GPa, respectively, which meets the requirements of the GFRP bar according to ACI 440.6M-5 [13], and CSA S807-10 [14]. Moreover, the tested specimens exhibited an ultimate tensile strain of 2.27 %, which is higher than the requirements of ACI 440.6M-5 [13], and CSA S807-10 [14] for GFRP bars.

3.2 Flexural Strength

The flexural strength of the BFRP bars was determined by testing five specimens with a span to diameter ratio of 17, according to ASTM D4476-14 [8]. The flexural strength is listed in Table 1. Figure 4 shows the test setup and Figure 5 shows the typical failure mode of BFRP bars in flexure.

Figure 4: Flexure Test Setup of BFRP Bars

Figure 5: Typical Failure Mode of BFRP Bars in Flexure

Since the flexural strength of the FRP bars has no specified limit in the specifications according to ACI 440.6M-5 [13], and CSA S807-10 [14], the value of flexure strength gives an indication for the quality control. However, the flexural strength achieved more than 70% of the pure tensile strength which is a good indicator of flexural strength.

3.3 Transverse Shear Strength

The transverse shear strength of the BFRP bars was determined by testing five specimens according to ASTM D7617-11 (2017) [10]. The transverse shear strength is listed in Table 1. Figure 6 shows the test setup and Figure 7 shows the typical failure mode of BFRP bars in transverse shear.

Figure 6: Transverse Shear Strength Test Setup

Figure 7: Typical Failure Mode of BFRP Bars in Transverse Shear

The BFRP bars showed an average transverse shear strength of 160± 9 MPa. This value is higher than the limit provided by ACI 440.6M-5 [13] of 124 MPa and equal to the limit provided by CSA S807-10 [14] of 160 MPa. Consequently, the BFRP bars satisfy both specifications requirements for the transverse shear.

3.4 Interlaminar Shear Strength

The interlaminar shear strength of the BFRP bars was determined by testing five specimens with a span to diameter ratio of 3.0 according to ASTM D4475-02 (2016) [9]. The transverse shear strength is listed in Table 1. Figure 8 shows the test setup and Figure 9 shows the typical failure mode of BFRP bars in interlaminar shear.

Figure 8: Interlaminar Shear Strength Test Setup

Figure 9: Typical Failure Mode of BFRP Bars in Interlaminar Shear

The BFRP bars showed an average interlaminar shear strength of 59.55 ± 2.57 MPa. The interlaminar shear strength of the FRP bars has no specified limit in the specifications according to ACI 440.6M-5 [13], and CSA S807-10 [14]. This value is a direct indicator of the quality of the fiber-resin interface, increasing this value means a better adhesion at the fiber-resin interface.

3.5 Bond Strength

The bond strength of the BFRP bars was determined by testing five specimens following ASTM D7913-14 [11], and ACI 440.3R-12 [12]. The bond strength is listed in Table 1. The test setup is shown in Figure 10 and Figure 11 shows the typical failure mode of BFRP bars in pull-out.

Figure 10: Pull-out Test Setup

Figure 11: Typical Failure Mode of BFRP Bars in Pull-out

The BFRP bars showed an average bond strength of 25± 1.5 MPa. This value is higher than the limit provided by ACI 440.6M-5 [13] of 9.6 MPa, and the limit provided by CSA S807-10 [14] of 8 MPa. Consequently, the BFRP bars satisfy both specifications requirements for the bond strength.

4. Conclusions and Recommendations

This paper presented the preliminary results of a study conducted to characterize the mechanical properties of basalt fiber-reinforced polymer (BFRP) bars. Based on the test results presented herein, the following conclusions are drawn:

- This study confirms that the developed basalt FRP (BFRP) bars meet the requirements of ACI 440.6M-5 and CSA S807-10 concerning their mechanical properties.
- The fiber-resin interface is a key parameter in the bond of the BFRP bars. The enhancement of the fiber-resin interface will lead to producing BFRP bars with improved bond properties.

This study aims to increase the applicability of using BFRP bars in constructions through providing a better understanding of the basalt FRP bar's mechanical characteristics.

The experimental study presented is limited to BFRP bars used in this study and should not be extended to other BFRP bar types.

5. References

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