

Applications of Basalt Fiber Reinforced Polymer (BFRP) Reinforcement for Transportation Infrastructure

Dr. Anil Patnaik
Associate Professor
Department of Civil Engineering
The University of Akron
Akron, OH44325-3905

ABSTRACT

The use of corrosion resistant fiber reinforced polymer (FRP) reinforcement is beneficial in transportation structures particularly those exposed to deicing salts, and/or located in highly corrosive environment. Glass, carbon and aramid fibers are commonly used in the manufacture of reinforcing bars for concrete applications. Significant research is documented in ACI 440 state-of-the-art report and in ACI 440.1R-06 report. Recent developments in fiber production technology allow the making of BFRP bars from basalt fiber which is made from basalt rock. Basalt fiber has good range of thermal performance, high tensile strength, resistance to acids, good electro-magnetic properties, inert nature, resistance to corrosion, radiation and UV light, vibration and impact loading. BFRP products are available in a variety of forms such as, straight rods, loops, two-dimensional mesh, and spirals.

Preliminary findings from recent research on concrete beams reinforced with BFRP bars are presented. The average tensile strength and modulus of elasticity of BFRP bars were determined from the test program and were found to be about 158 ksi, and 6,200 ksi, respectively. Thirteen test beams were tested over a span of 5 feet. The moment strength of concrete beams reinforced with BFRP bars was found to be consistent with the mechanical properties of BFRP bars. The design recommendations of ACI440.1R-06 are mostly adequate to predict the moment strength of concrete beams reinforced with BFRP bars. However, comprehensive studies on shear strength (diagonal and punching), and deflection characteristics of members reinforced with BFRP bars are required for potential use in transportation structures. Research needs also exist in the area of durability of BFRP reinforced concrete members.

INTRODUCTION

Fiber reinforced polymer (FRP) composite bars and fabric sheets are currently being used as internal or external reinforcement for concrete members in many structural systems. American Concrete Institute Committee 440 published a revised state-of-the-art report (ACI 440R-07¹) and several other reports including ACI 440.1R-06² for the design and construction of structural concrete internally reinforced with FRP bars. These reports provide design guidelines and recommendations, and provide information on the use of common FRP materials such as, glass (GFRP), aramid (AFRP) and carbon (CFRP).

High strength, light weight, non-magnetic and non-corrosive properties, and good fatigue endurance are among some of the favorable properties that would favor the use of FRP bars. High initial cost, low modulus, linear stress-strain behavior until failure, and durability issues are some obstacles to the adoption of FRP materials in transportation infrastructure.

Many demonstration or commercial projects in the United States and overseas are also reported¹. However, there remain questions regarding the performance of GFRP and AFRP in highly alkaline environment within concrete. CFRP bars are too expensive to be implemented in normal cost sensitive civil engineering structures. Furthermore, cost of production of FRP bars is high because FRP bars that are currently available in the market are manufactured by pultrusion method.

A new type of reinforcing bars made from basalt fiber (BFRP) has good potential to provide benefits that are comparable or superior to GFRP, and significantly cost effective compared to CFRP. However, very little research has been performed in the United States and elsewhere on concrete members internally reinforced with BFRP bars. A new wet layup process was recently developed and patented by a Norwegian company. FRP bars made using this new process have not been researched so far. Preliminary results of an ongoing research project at the University of Akron (Ohio) on flexural performance of concrete beams internally reinforced with BFRP bars that were manufactured using wet layup method are presented in this paper.

BASALT FIBER: A NEW TYPE OF FIBER

Basalt (solidified volcanic lava) is known for its resistance to high temperatures, strength and durability. Basalt fiber is extruded from molten basalt rock at diameters generally between 13 to 20 μm. Basalt fiber products are available in commercial quantities from various sources including from China. BFRP fiber products are available in various forms such as bars, mesh, cages, spirals, fabric, and chopped fiber, as shown in Fig. 1 and are useful as reinforcement in concrete structures^{3,4}.

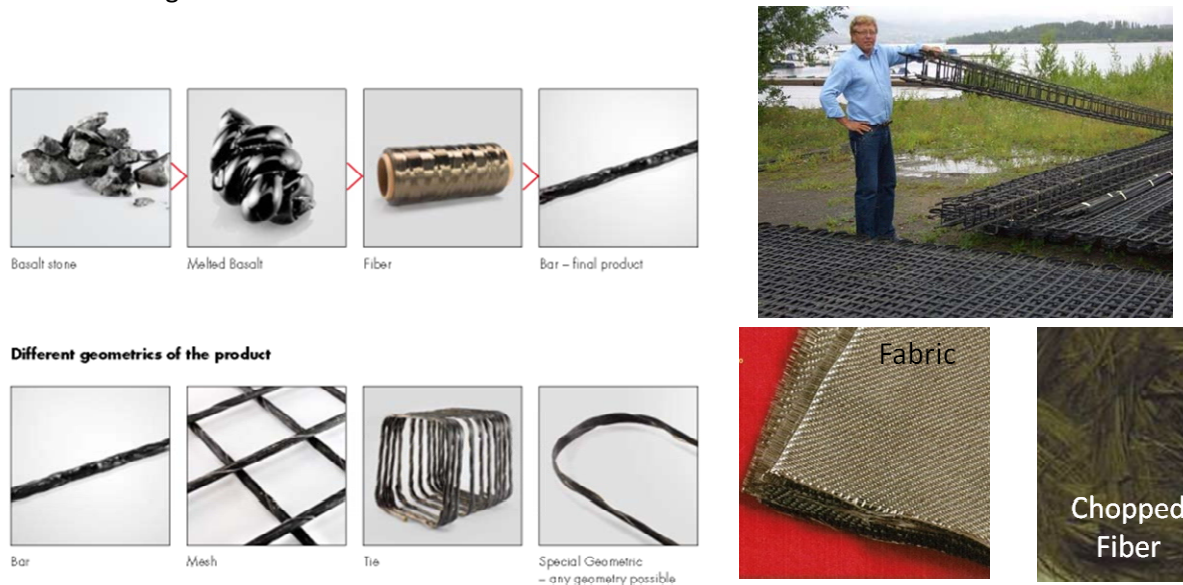


Fig. 1 Various Forms of BFRP Fiber Products

Table 1 Properties of Basalt Fiber

Specific gravity	2.6
Tensile strength	2500 MPa (360 ksi)
Elastic Modulus	89 GPa (12,900 ksi)
Rupture strain	3.15%

Basalt fiber is environmentally and ecologically harmless, and free from carcinogens and other health hazards. In construction industry, basalt fiber can be provided at a cost considerably less than carbon, silica and other fibers. The properties that are superior in basalt fiber are: good range of thermal performance (-435° F to 1760° F), high tensile strength, high resistance to alkalis and acids, superior electro-magnetic properties, inertness, resistance to corrosion, resistance to radiation and UV light, and good resistance to vibration. Some relevant mechanical properties of basalt fiber are summarized in

Table 1. BFRP bars included in the current research project were made using wet layup method. The cost of production is believed to be significantly reduced because of the switch in production method from pultrusion to a simple wet layup method. Fig. 2 shows a schematic for the new production process.

MECHANICAL PROPERTIES

The mechanical properties that are of interest in structural design are the tensile strength, modulus, and rupture strain, and their standard deviation⁵. These three mechanical properties and the respective standard deviations were established. A summary of the test results is shown in Table 2.

Table 2 Summary of Tensile Properties of BFRP Bars

Bar	Diameter mm (inch)	Area		$f_{f,ave}$		$E_{f,ave}$	
		mm ²	inch ²	MPa	ksi	GPa	ksi
R4	4.3 (0.17)	14.5	0.0225	1,110	160.9	41.1	5,950
R7	7.1 (0.28)	39.7	0.0615	1,084	157.2	41.4	6,030
R10	9.8 (0.39)	75.6	0.1172	1,067	154.7	45.1	6,530

$f_{u,ave}$ = Average tensile strength $E_{f,ave}$ = Average modulus of elasticity

BEAM TESTS

Thirteen beams were made to a total length of 7 feet each. The test beams were tested over a span of 5 feet (Fig. 3). The typical failure mode of the test specimens is shown in Fig. 4. The test beams mostly failed in a ductile manner with large mid-span deflections.

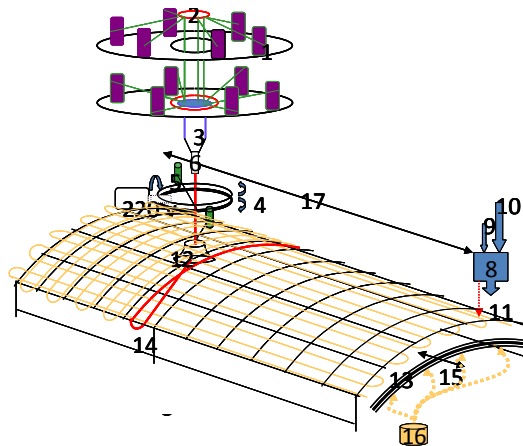


Fig. 2 Schematic of a New Wet Layup Manufacturing Process (Figure provided by ReforceTech, AS)

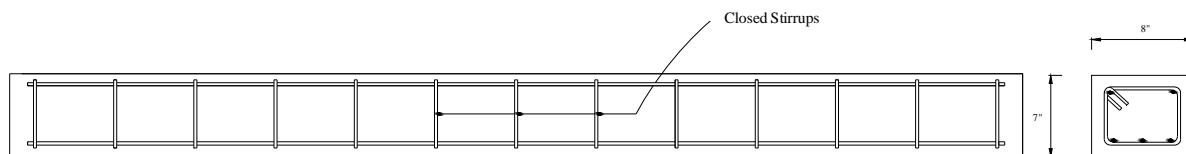


Fig. 3 Typical Reinforcement Details (Left) and Cross-Section of a Test Beam (Right)

The failure loads of test beams are shown in Fig. 5. The figure also shows the load predicted for each test beam by using ACI 440.1R-06² recommended method for the determination of nominal moment strength of concrete beams reinforced with other common types of FRP bars. The failure loads obtained from tests for most beams are either greater than or within about 3% of the strengths predicted using ACI 440.1R-06. A typical load-deflection curve is shown in Fig. 6. Typical development of strain in BFRP bars with load is also shown in Fig. 6.

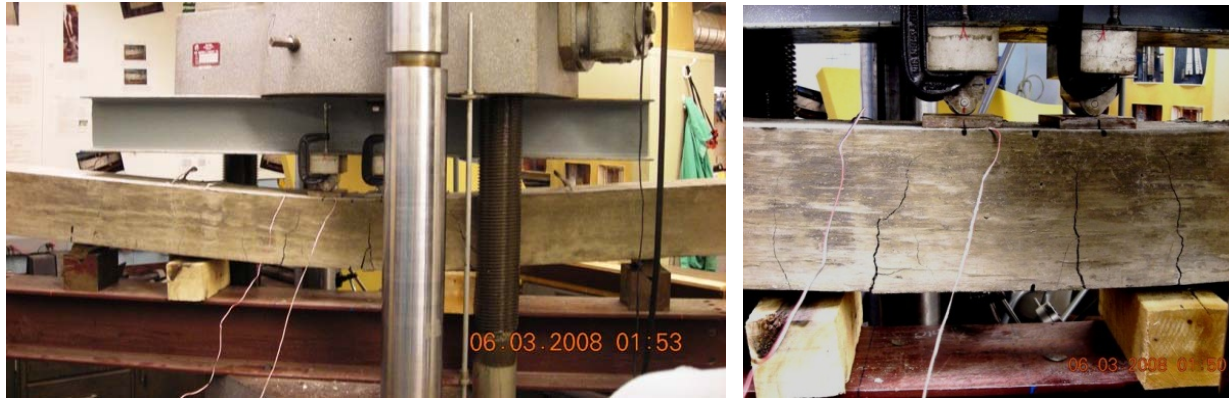


Fig. 4 Typical Failure Mode of Test Beams and Crack Pattern

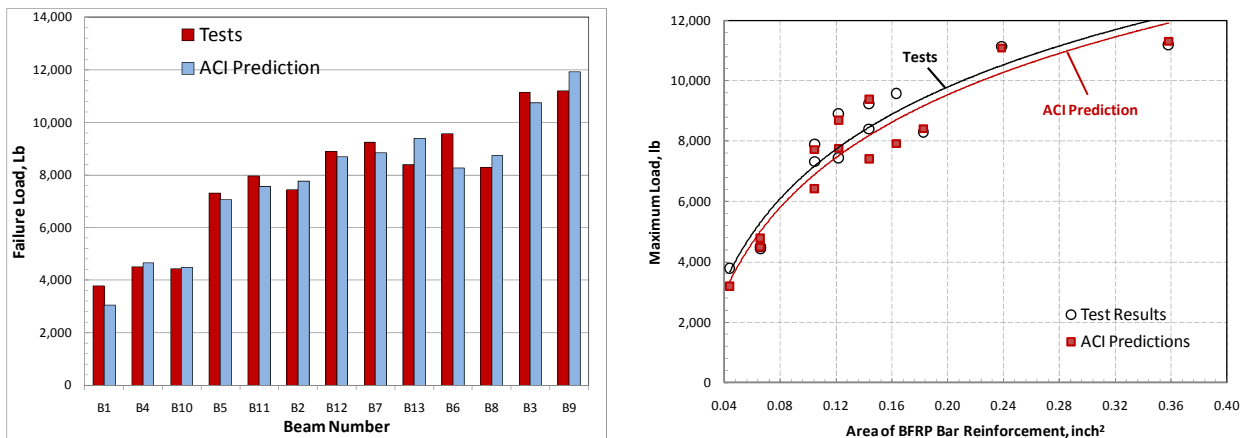


Fig. 5 Failure Loads Obtained from Tests Compared with ACI 440.1R-06² Prediction

DISCUSSION

From Fig. 5, it can be seen that most beams were able to achieve the moment strength that is predicted using the ACI 440.1R-06 method that is applicable to other common types of FRP bars. The development of load carrying capacity with increased area of reinforcement is also shown in Fig. 5. The two curves indicate that there generally exists a reasonable level of match between the test results and the prediction made using ACI 440.1R-06 approach for the determination of predicted moment strength of concrete beams reinforced with other common FRP bars.

Evenly spaced crack development in test beams revealed that the wet layup production process of BFRP bars may have provided the required roughness and unevenness resulting in adequate bond between the bars and the surrounding concrete. The large midspan deflections recorded for the test beams at failure also indicate that the concrete beams reinforced with BFRP bars performed in a ductile manner.

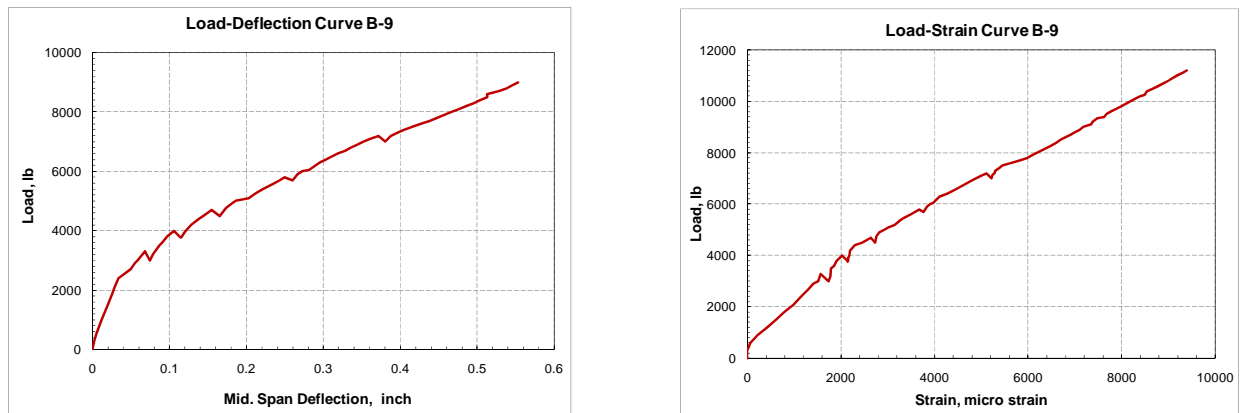


Fig. 6 Typical Load Deflection and Load-Strain Curves

CONCLUDING COMMENTS

The preliminary research on basalt FRP bars and concrete beams reinforced with such bars presented in this paper indicate that BFRP bars produced by wet layup method are performing as well as other types of common FRP bars. Concrete beams reinforced with BFRP bars achieved moment strengths that are consistent with the relevant properties of the constituent materials and are comparable to those predicted using ACI 440.1R-06. Concrete beams reinforced with BFRP bars behaved in a ductile manner exhibiting large deflection at failure. However, comprehensive studies are required for establishing flexural, shear, deflection, and cracking characteristics of members reinforced with BFRP bars, and the corresponding durability performance.

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