Basalt FRP Reinforcement in Concrete Topping Slabs in a Commercial Building

A sustainable and durable solution

by Alvaro Ruiz Emparanza, Brett McMahon, and Antonio Nanni

Fiber-reinforced polymer (FRP) bars are a noncorrosive and long-lasting alternative to traditional steel reinforcing bars used in concrete structures. These composite bars are made of longitudinally aligned fibers embedded in a resin matrix using a manufacturing process called pultrusion. FRP bars have been used in civil engineering structures for over three decades. Glass fiber is the most-used fiber type because of its availability and low cost. However, because the physical properties of basalt fibers exceed those of glass,[1,2] and because the cost difference between the two fiber types is marginal, interest in this fiber type has been increasing. With a growing supply of basalt fibers in the United States, basalt FRP (BFRP) bars are becoming economically feasible.[3]

BFRP bars provide a high tensile strength (over three times higher than Grade 60 steel for equivalent bar diameters). As with glass FRP (GFRP) bars, BFRP bars are lightweight (one-fourth the weight of steel), electrically nonconductive, and transparent to electromagnetic fields. The main advantage of these composites, however, is the high corrosion resistance, even when exposed to harsh environments like seawater.[1,4-6] As with any other FRP composite, BFRP bars are linear elastic to failure and do not exhibit a plastic plateau like mild steel. Further, the elastic modulus of BFRP bars is approximately one-third of that of steel reinforcement. When compared to other FRP types, BFRP bars fall between glass and carbon for both strength and stiffness. In comparison to FRP bars made of E-CR glass, BFRP bars have a slightly higher elastic modulus and strength as well as greater chemical stability.[1,4]

Use of FRP Bars

Historically, FRP bars have been most frequently used in transportation infrastructure rather than in buildings. The main reason behind this is the goal of departments of transportation (DOTs) to increase the service life and reduce maintenance costs of bridges and other highway structures. For example, Al-Khafaji et al.[7] evaluated 11 GFRP reinforced bridges after being in service for 15 to 20 years and, from the extracted coupons, almost no GFRP degradation was seen even though the bars used in these projects were made with E glass rather than the current E-CR glass type, a more recent boron-free evolution for improved corrosion resistance. In fact, while E glass is the most widely used glass fiber formula in the world, it contains boron and fluorine, two compounds that are trapped in particles released into the atmosphere during manufacturing, causing environmental pollution. Conversely, E-CR glass fibers are boron- and fluorine-free and have better mechanical properties, higher heat resistance, waterproof resistance, and higher surface resistance than E-glass fibers. Since 2005, E-CR glass fiber has been produced in accordance with ASTM D578/D578M, "Standard Specification for Glass Fiber Strands."

Lately, building contractors have expressed an increased interest in FRP reinforcement based on the positive results from their use in infrastructure projects. In addition to durability, a very important advantage for contractors is the light weight of the material, which makes the transportation, handling, and installation easy and cost-effective. However, material specifications, design guides, and standards published prior to 2018 only make reference to GFRP reinforcement:

- ACI 440.1R-15, "Guide for the Design and Construction of Structural Concrete with Fiber-Reinforced Polymer (FRP) Bars"[8];
- ASTM D7957/D7957M-17, "Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement"; and

- "AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete."[9]

Fortunately, two more recent documents include the use of BFRP reinforcement:

- AC454, "Acceptance Criteria for Fiber-Reinforced Polymer (FRP) Bars for Internal Reinforcement of Concrete Members"[10]; and
- Section 932-3 in Florida DOT "Standard Specifications for Road and Bridge Construction" (Standard Specifications).[11]

Of particular relevance to buildings is the acceptance criteria AC454 issued by ICC Evaluation Service (ES), which provides required test methods and evaluation provisions for quantifying performance characteristics of GFRP and BFRP bars when used as flexural reinforcement in structural concrete members such as beams, shallow foundations, and one-way or two-way slabs; and as shear reinforcement for flexural members, or longitudinal reinforcement for columns and walls. The purpose of AC454 is for GFRP and BFRP bars to be recognized as compliant with requirements of 2021 IBC, Section 104.11,[12] and 2021 IRC, Section R104.11.[13]

In addition, FDOT Standard Specifications, Section 932-3, now provides material requirements for application of GFRP and BFRP bars in highway and related construction. It is referenced in the FDOT *Structures Manual*, V. 4, which includes design methodology for concrete structures reinforced with GFRP and BFRP bars:

"…The design of all concrete members containing GFRP reinforcing bars shall be in accordance with the AASHTO LRFD Bridge Design Guide Specifications for GFRP Reinforced Concrete. For BFRP use the same design criteria as GFRP."[14]

The Avocet Tower

The Avocet Tower is a side-by-side office and hotel structure located at 7373 Wisconsin Avenue, Bethesda, MD, USA. The owner, Stonebridge, a real estate developer, is also located in Bethesda, MD. The 22-story office building is topped with a rooftop terrace with views overlooking all of Bethesda, extending to Rockville, MD, and Washington, DC, USA. Contiguous with the office building is an 18-story Marriott AC Hotel. The tower also has two below-grade and five above-grade parking levels.

Miller & Long Co., Inc., was the subcontractor for the cast-in-place concrete. The project required approximately 37,000 yd^3 (28,300 m^3) of concrete, with an estimated 738,000 ft^2 (68,600 m^2) of supported slab. Typical floors were post-tensioned steel-reinforced concrete structural slabs with a thickness of 9 in. (230 mm). The topping slabs, however, were reinforced with BFRP bars. Miller & Long was responsible for selecting and placing the BFRP reinforcement. This article discusses the design and construction of topping slabs.

Topping Slabs

Material properties

The topping slabs were constructed using BFRP-reinforced concrete. Prior to the construction of the slabs, the concrete and the BFRP reinforcement were tested by independent materials laboratories. Figure 1 shows No. 3 BFRP reinforcement that was used for this project.

The concrete was tested in accordance with ASTM C39/C39M, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," and had a compressive strength of 4875 psi (33.6 MPa) after 28 days. The properties of the BFRP bars were tested according to various ASTM standards listed in Table 1. It was ensured that the values exceeded those defined by AC454.

Design

The design of the topping slabs was performed according to ACI 440.1R-15, Section 13.2, even though it is recognized

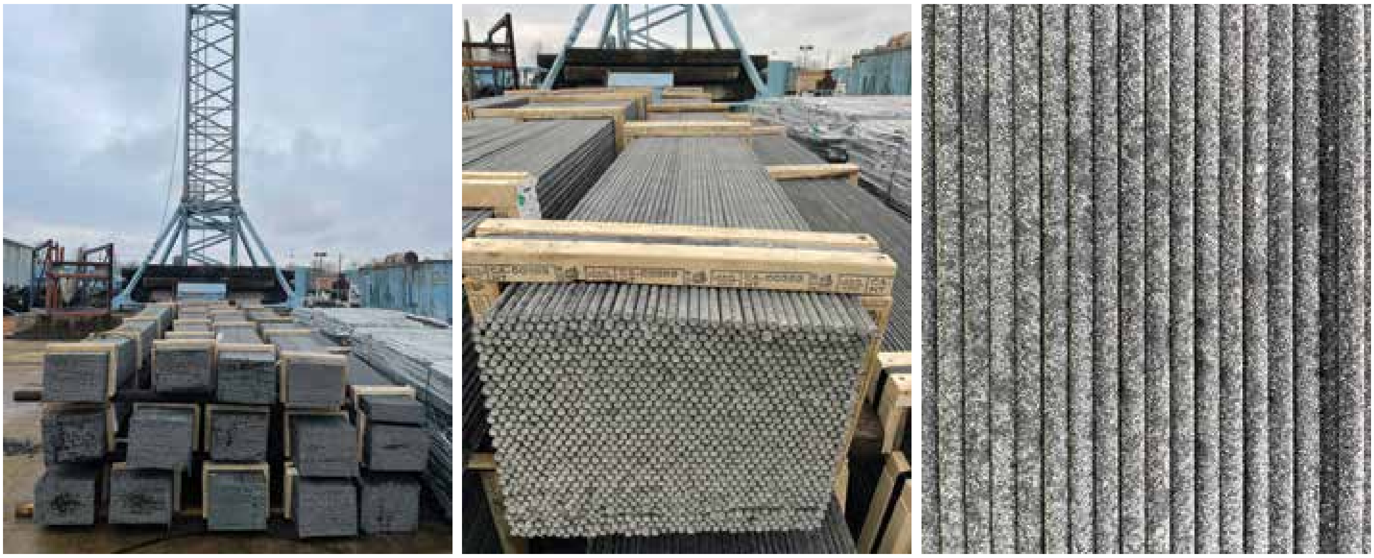

Fig. 1: BFRP bars used to reinforce topping slabs

Table 1:
Properties of No. 3 BFRP bars used in topping slabs

Test type	Test method	Test results	AC454 requirements
Minimum guaranteed tensile load*	ASTM D7205‡	26.4 kip	13.2 kip
Nominal guaranteed tensile strength†	ASTM D7205	240.1 ksi	120 ksi
Modulus of elasticity†	ASTM D7205	8850 ksi	6500 ksi
Measured area	ASTM D792§	0.132 in.^{2}	0.104 to 0.161 in.^{2}
Fiber content by mass	ASTM D2584ǁ	83.1%	> 70%

*Value computed as average minus three standard deviations

†Based on nominal area of 0.11 in.^{2} (71 mm^2)

‡ASTM D7205/D7205M, "Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars"

§ASTM D792, "Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement"

ǁASTM D2584, "Standard Test Method for Ignition Loss of Cured Reinforced Resins"

Note: 1 kip = 4.45 kN; 1 ksi = 6.89 MPa; 1 in.^{2} = 645 mm^2

that the guide only references GFRP bars. The slabs were designed using BFRP bars as temperature and shrinkage reinforcement. Even though the slabs were assumed to be uncracked under service loading, reinforcement was provided to: a) limit possible crack spacing and width; b) increase the ability to transfer load at joints; c) permit the use of wider joint spacing; and d) provide a reserve strength in case shrinkage or temperature cracking would occur. Due to the lower modulus of elasticity of BFRP bars compared to steel, the design was performed based on strain rather than stress level, as in the case of steel reinforcement. The strain in the BFRP reinforcement was limited to 0.0012.

The thickness of the topping slabs varied from a minimum of 3 in. (76 mm) to a maximum of 5 in. (127 mm). The slabs were reinforced with No. 3 BFRP bars placed 12 in. (305 mm) on-center (o.c.) in both directions, as shown in Fig. 2. The slabs were supported by a Type E-EPS19 polystyrene fill (per ASTM D6817/D6817M, "Standard Specification for Rigid Cellular Polystyrene Geofoam") with a compressive strength value of 835 psf (40 kPa). Portions of this plaza were designed for fire truck loading.

In total, the topping slabs covered a surface of 5160 ft^2 (480 m^2) and were reinforced with about 15,000 ft (4570 m) of No. 3 BFRP bars. Figure 3 shows the plan view of the topping slabs.

Construction

The topping slabs were built in two phases of equally large surfaces due to the overall project schedule. The BFRP bars were placed considerably fast due to their light weight. Also, because BFRP reinforcement comes back to its original position, provided that the applied load does not exceed its ultimate strength, walking over the installed reinforcement wasn't an issue. Figure 4 shows the installation process of the BFRP reinforcement. Notice that the worker in the top right photo is carrying a bundle of 20, 20 ft (6 m) long bars.

Once the reinforcement was installed, due to a difficult access, the concrete was placed using a concrete pump (Fig. 5).

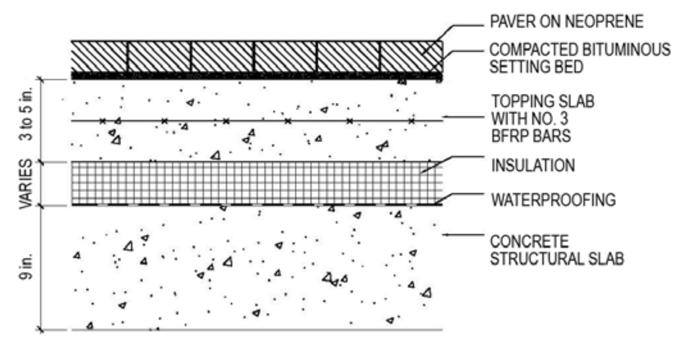

Fig. 2: Section of topping slab (Note: 1 in. = 25 mm)

The slabs were finished by the specialized crew of finishers to get a smooth surface. After the concrete work was finished, the slabs were properly cured to avoid potential shrinkage cracking.

Environmentally Friendly Reinforcement

The most frequently used reinforcement for concrete is made of carbon steel. The main constituent in the production of steel is iron ore. Both the mining and the making of steel requires high energy and generates pollution. On average, 1.74 tons (1.58 tonnes) of CO_2 are emitted for every ton of steel produced in the United States, making steel production a major contributor to global warming.[15] The main ingredient of BFRP bars, however, is basalt rock, which is an inert organic volcanic rock. Basalt fibers are manufactured solely from basalt rock without additional chemicals and there is no waste during production. Basalt fibers are inert, recyclable, and noncombustible.[16] Compared to steel, the energy required for basalt fiber production is significantly lower. While 14 kWh/kg are needed on average to produce steel in an electric furnace, basalt fiber requires just 5 kWh/kg, reducing the energy consumption by about 65%.[16]

Even with about 20% by mass of thermoset resin needed for the manufacturing of BFRP bars, they are an environmentally friendly reinforcement for concrete.

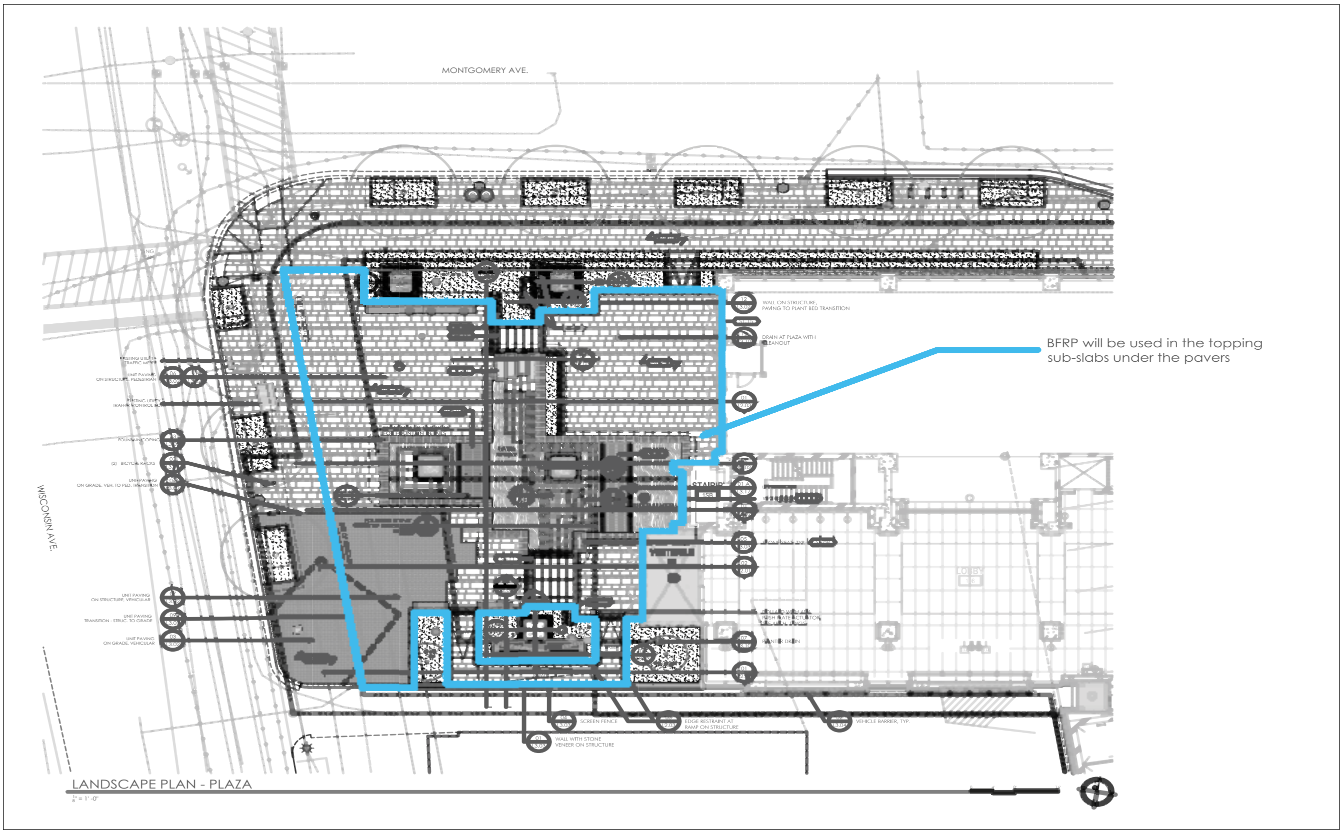

Fig. 3: Plan view of topping slabs

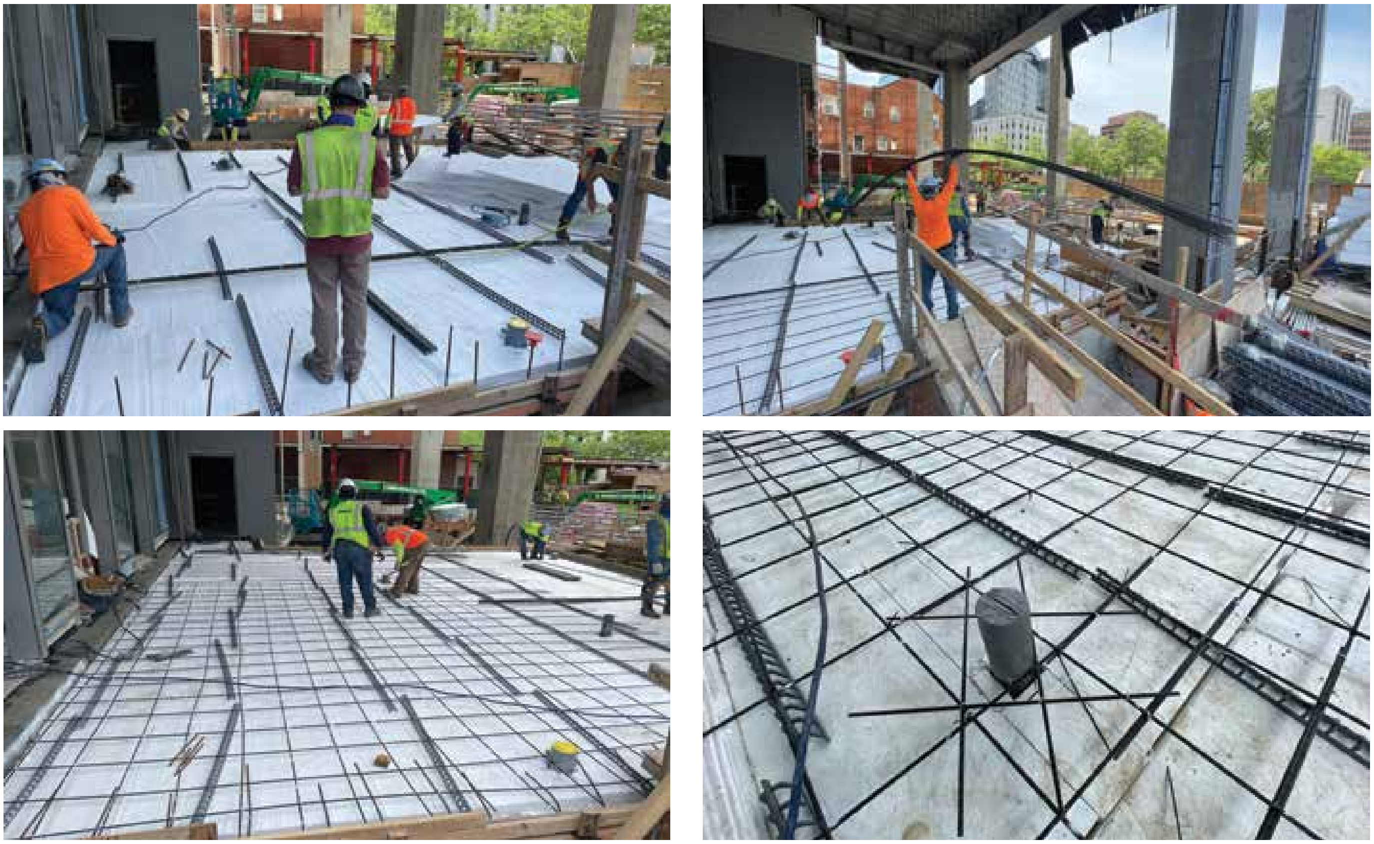

Fig. 4: Installation of No. 3 BFRP reinforcement for one of the topping slabs



Fig. 5: Concrete placement for one of the topping slabs

Inman et al.[17] conducted a study on the mechanical and environmental assessment and comparison of BFRP and steel bars in concrete beams. The life-cycle assessment (LCA) results showed that the BFRP-reinforced beams performed significantly better across all 18 environmental indicators evaluated in the study (including ozone depletion, acidification, and eutrophication) compared to the steel-reinforced concrete beams. In terms of global warming potential (GWP), a reduction of 62% in climate change emissions was inferred when using BFRP reinforcement over conventional steel.[17] This would make BFRP a green solution for concrete reinforcement.

Benefits of Using BFRP Bars

BFRP reinforcement provides multiple benefits to contractors due to its light weight and corrosion resistance. The main advantages are:

- **Transportation:** With the weight of BFRP bars being one-fourth of that of carbon steel reinforcement, the transportation costs can be reduced by about 60%;
- **Handling and installation:** The handling and installation of BFRP bars is fast, efficient, economical, and therefore more sustainable. The light weight of BFRP bars allows for the use of smaller equipment on site (less fuel consumption) and a reduced workforce. In addition, the handling is safer for the workers (less injuries), which equates to a reduction in cost. On the jobsite, bars can easily be cut if needed with a regular saw, and once cut, the ends of the bars do not need to be specially treated as would be the case for epoxy-coated steel bars. When stepping on the reinforcing mats during installation, there is no yielding and permanent displacement because BFRP bars are linear elastic until failure. Therefore, the installation of the reinforcement becomes less tedious and more accurate; and
- **Sustainable construction:** The use of noncorrosive reinforcement allows contractors to provide customers long-lasting and "green" built structures, adding significant value to projects and avoiding potential deterioration claims during the service life.

In Summary

The Avocet Tower in Bethesda, MD, is a 22-story tall building comprised of a Marriot AC Hotel and office spaces. The 5160 ft^2, 3 to 5 in. thick topping slabs in the tower were reinforced using No. 3 BFRP bars placed 12 in. o.c. in both directions. The use of BFRP bars significantly accelerated the construction process and allowed for reduced cost in transportation and installation of the reinforcement due to the light weight of the composite bars. Because of the lower carbon footprint of BFRP bars and the extension of the service life, the slabs are considered a "green" structure.

Project credits

Owner: Stonebridge, Bethesda, MD
Engineer of record: Cagley & Associates, Rockville, MD
Concrete subcontractor: Miller & Long Co., Inc., Bethesda, MD
Manufacturer of BFRP bars: Pultrall, Thetford Mines, QC, Canada

References

1. Ali, A.H.; Mohamed, H.M.; Benmokrane, B.; ElSafty, A.; and Chaallal, O., "Durability Performance and Long-Term Prediction Models of Sand-Coated Basalt FRP Bars," *Composites Part B: Engineering*, V. 157, Jan. 2019, pp. 248-258.

2. Kampmann, R.; Telikapalli, S.; Emparanza, A.R.; Schmidt, A.; and Dulebenets, M.A., "Tensile Properties of Basalt Fiber-Reinforced Polymer Reinforcing Bars for Reinforcement of Concrete," *ACI Materials Journal*, V. 118, No. 1, Jan. 2021, pp. 111-126.

3. Schmidt, A.; Kampmann, R.; Telikapalli, S.; Emparanza, A.R.; and De Caso Y Basalo, F., "Basalt FRP Production—Market Analysis and a State-of-the-Art Report," fib *Symposium 2019—Innovations in Materials, Design and Structures*, Kraków, Poland, May 27-29, 2019.

4. Dhand, V.; Mittal, G.; Rhee, K.Y.; Park, S.-J.; and Hui, D., "A Short Review on Basalt Fiber Reinforced Polymer Composites," *Composites Part B: Engineering*, V. 73, May 2015, pp. 166-180.

5. Mohamed, O.A.; Al Hawat, W.; and Keshawarz, M., "Durability and Mechanical Properties of Concrete Reinforced with Basalt Fiber-Reinforced Polymer (BFRP) Bars: Towards Sustainable Infrastructure,"

Polymers, V. 13, No. 9, May 2021, 23 pp.

6. Wu, G.; Wang, X.; Wu, Z.; Dong, Z.; and Xie, Q., "Degradation of Basalt FRP Bars in Alkaline Environment," *Science and Engineering of Composite Materials*, V. 22, No. 6, 2015, pp. 649-657.

7. Al-Khafaji, A.F.; Haluza, R.T.; Benzecry, V.; Myers, J.J.; Bakis, C.E.; and Nanni, A., "Durability Assessment of 15- to 20-Year-Old GFRP Bars Extracted from Bridges in the US. II: GFRP Bar Assessment," *Journal of Composites for Construction*, V. 25, No. 2, Apr. 2021.

8. ACI Committee 440, "Guide for the Design and Construction of Structural Concrete with Fiber-Reinforced Polymer Bars (ACI 440.1R-15)," American Concrete Institute, Farmington Hills, MI, 2015, 83 pp.

9. "AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete," second edition, American Association of State Highway Officials, Washington, DC, 2018, 121 pp.

10. "Acceptance Criteria for Fiber-Reinforced Polymer (FRP) Bars for Internal Reinforcement of Concrete Members," AC454, ICC Evaluation Service, Inc., Country Club Hills, IL, Dec. 2020, 10 pp.

11. "Standard Specifications for Road and Bridge Construction," Florida Department of Transportation, Tallahassee, FL, 2021, 1233 pp.

12. "2021 International Building Code (IBC)," International Code Council, Country Club Hills, IL, 2021, 833 pp.

13. "2021 International Residential Code (IRC)," International Code Council, Country Club Hills, IL, 2021, 1109 pp.

14. "Fiber Reinforced Polymer Guidelines (FRPG)," *Structures Manual*, V. 4, Florida Department of Transportation, Tallahassee, FL, 2021, 16 pp.

15. Hasanbeigi, A.; Arens, M.; Cardenas, J.C.R.; Price, L.; and Triolo, R., "Comparison of Carbon Dioxide Emissions Intensity of Steel Production in China, Germany, Mexico, and the United States," *Resources, Conservation and Recycling*, V. 113, Oct. 2016, pp. 127-139.

16. De Fazio, P., "Basalt Fiber: From Earth an Ancient Material for Innovative and Modern Application," *Energia, Ambiente e Innovazione*, V. 3, May-June 2011, pp. 89-96.

17. Inman, M.; Thorhallsson, E.R.; and Azrague, K., "A Mechanical and Environmental Assessment and Comparison of Basalt Fibre Reinforced Polymer (BFRP) Rebar and Steel Rebar in Concrete Beams," *Energy Procedia*, V. 111, Mar. 2017, pp. 31-40.

Note: Additional information on the ASTM standards discussed in this article can be found at **www.astm.org**.

Selected for reader interest by the editors.

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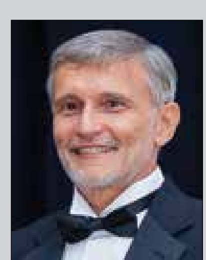

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