1-1-2007

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DOI: 10.5703/1288284315719

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Recommended Citation

ECT Team, Purdue, "FRP Rebar (AFRP, CFRP, GFRP)" (2007). *ECT Fact Sheets*. Paper 10.
<http://dx.doi.org/10.5703/1288284315719>

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FRP REBAR (AFRP, CFRP, GFRP)

THE NEED

Reinforced Concrete is a very common building material for the construction of facilities and structures. As complement to concrete's very limited tensile strength, steel rebar has been an effective and cost-efficient reinforcement. However, insufficient concrete cover, poor design or workmanship, and presence of large amounts of aggressive agents including environmental factors all can lead to cracking of the concrete and corrosion of the steel rebar. For instance, in the USA, almost 40% of bridges are structurally deficient or functionally obsolete, and the percentage is increasing, according to the Federal Highway Administration (Griffiths 2000). For many years, there have been many studies on this corrosion issue, and the interest in FRP (Fiber Reinforced Polymer) has arisen recently as prospective substitute for steel. Careful consideration on potential of FRP rebar to fill the cost and performance needs may suggest appropriate solutions.

**FIGURE 1 NOTRE-DAME HOSPITAL USED FOR MAGNETIC NEUTRALITY IN MRI ROOM
(PULTRALL, ADS COMPOSITES GROUP, 1995)**

THE TECHNOLOGY

Recently, composite materials made of fibers embedded in a polymeric resin, also known as fiber-reinforced polymers, have become an alternative to steel reinforcement for concrete structures. Aramid fiber reinforced polymer (AFRP), carbon fiber reinforced polymer (CFRP), and glass fiber reinforced polymer (GFRP) rods are the commercially available products for the construction industry. They have been proposed for use in lieu of steel reinforcement or steel prestressing tendons in nonprestressed or prestressed concrete structures (ACI 440R 2006). The problems of steel corrosion are avoided with the use of FRPs because FRP materials are nonmetallic

and noncorrosive. In addition, FRP materials exhibit several properties including high tensile strength, that make them suitable for the use as structural reinforcement. Furthermore, codes and design guide provisions have been recently prepared for the use of FRP bars in concrete structures for bridges and buildings (ACI 440H 2000; CSA 2000; ISIS-Canada 2000).

**FIGURE 2 CAISSONS AND PORT FACILITIES
(PULTRALL, ADS COMPOSITES GROUP)**

The bond characteristics are responsible to transfer the load from concrete to reinforcement and to develop the required stress in the reinforcement for an equilibrium, particularly when concrete is cracked. Service limits in FRP reinforced concrete elements such as deflection, crack width and crack spacing are directly influenced by the bond properties of the reinforcement in concrete. Fiber reinforced polymer bars are anisotropic materials. Factors such as type and volume of fiber and resin, fiber orientation and quality control during the manufacturing play a major role in the mechanical characteristics. In the case of Carbon FRP rebar (CFRP Isorod bar from Pultrall, ADS Composites Group), when comparing a steel bar of 11.3 mm diameter with CFRP rebar with similar diameter of about 9.5 mm, the results shows that the tensile stress-strain curves of the CFRP bar are linear up to failure (All FRP bars are linear elastic to failure). The ultimate tensile strength is at least 1500 MPa, 3 times that of steel rebar. The modulus of elasticity of the CFRP bar is 128 GPa, about 65% that of steel. The CFRP bar exhibited almost the same bond strength to concrete as 11.3 mm diameter steel bar. (Benmokrane et al. 2001) As for Glass FRP bar (ASLAN 100 GFRP bar from Hughes Brothers, Inc.), tensile strength of 9 mm GFRP bar is 760 MPa, and the Modulus of Elasticity is 40.8 GPa, much lower than that of steel.

**FIGURE 3 HALL'S HARBOR - WORLD'S FIRST FULLY COMPOSITE REINFORCEMENT WARF
(PULTRALL, ADS COMPOSITES GROUP; HUGHES BROTHERS, INC.)**

Fiberglass rebar may be a suitable alternative to steel reinforcing in:

- Architectural Concrete: cast stone, architectural cladding, balusters, column facades, window lentils, architectural precast elements, hand railing, and statuary and fountains, etc.
- Concrete exposed to de-icing salts in: bridge decks, railroad grade crossings, median barriers, parking garage elements, and salt storage facilities, etc.
- Concrete exposed to marine salts in: seawalls, water breaks, buildings & structures near waterfront, aquaculture operations, and floating marine docks, etc.
- Concrete used near electromagnetic equipment such as: MRI rooms in hospitals, airport radio & compass calibration pads, and concrete near high voltage cables, transformers, substations, etc.

FIGURE 4 DRY DOCK #4 PEAL HARBOR, HAWAII (HUGHES BROTHERS, INC)

THE BENEFITS

- Impervious to chloride ion and chemical attack
- Tensile strength greater than steel
- 1/4th weight of steel reinforcement
- Transparent to magnetic fields and radio frequencies
- Electrically and thermally non-conductive

Based on features above, FRP bars appear to be promising alternative to steel reinforcement in concrete structures such as marine structures, parking structures, bridge decks, highway under extreme environments, and structures highly susceptible to corrosion and magnetic fields.

STATUS

The earliest commercial uses of FRP composite rebar are approximately twenty-five years old. These original applications were for non-magnetic or radio-frequency transparent reinforcements for magnetic resonance imaging (MRI) medical equipment and specialized defense applications. FRP composite rebars have emerged as the industry standard for this application, eclipsing stainless steel in recent years. As recently as the 1990s, the deteriorating state of the U.S. infrastructure, particularly vehicular highway

bridges, caused alternative reinforcements to be considered. Parallel interest in Europe and Japan has helped to make FRP composite rebar an international research topic. According to ACI 440H, the Japanese lead in this field, with more than 100 demonstration projects reported in the literature. One of most important developments is the publication of ACI440.3R-04 published to support the ACI 440 design guides, with the understanding that in due time these test methods would transition to the more formal ASTM body. The document is available from ACI and provides the practicing engineering with the necessary information to implement these new FRP bars. This transitioning is now occurring and documents such as ASTM D7205 now describe test methods for determining tensile, modulus and strain properties of FRP bars. Several other test methods are also in the process of being printed in the ASTM consensus reviewed format. In addition, FRP Rebar Manufacturers Council (Chairman: Doug Gremel) was formed by the manufacturers listed on the 'Points of Contact' with the objective of fostering quality assurance and other industry standards amongst manufacturers.

The Canadian Highway bridge design code, CSA - S6-06 now includes provisions which allow for the use of GFRP rebar. Consequently, a number of bridges in Canada are being built in on a more routine basis. The largest of these projects to date is the "Floodway Bridge" near Winnipeg. This is a significant bridge structure by any measure but more so due to fact that it was built using the "steel free deck" concept using all GFRP bars in the concrete above the girders.

BARRIERS

The cost of FRP rebar in \$/ft is typically higher than conventional steel rebar. Carbon FRP is usually more expensive then GFRP. [Click here](#) to find a detailed cost catalog for FRP rebar. It should be noted that it is not possible to make a direct substitution from steel bars to FRP without applying the design principles of the appropriate guide. In general, the cost impact to use GFRP bars in a bridge deck is only raising the cost of the deck by something on the order of 2 to 5% these days. So, to utilize GFRP bars and potentially gain many extra years of service life may not an expensive alternative.

- The cost is \$3 to \$4/lb (including approx. \$1/lb of raw material cost) in case of Glass FRP bar, and Carbon FRP is usually more expensive. (cf. Epoxy coated rebar costs \$0.32/lb).
- Due to the lack of well-established standards, a wide variety of FRP bars is today commercialized, going from the simple smooth bars to bars treated to improve bond characteristics. Therefore, a better understanding of mechanical properties and bond behavior is needed for a rational approach to the design of FRP reinforced structures.
- Field bends are not allowed, and not-weldable, so consideration on differences in construction operations of regular steel rebar should be applied from the design phase.
- Lack of familiarity by practicing engineers can cause lower productivity than prospected.

POINTS OF CONTACT

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REFERENCES

1. Marshall Industries Composites, Inc. Website: <http://www.c-bar.com>.
2. Hughes Brothers, Inc. Website: <http://www.hughesbros.com>.
3. Griffiths, J. R. "Plastic Highway Bridges", Cambridge Scientific Abstracts, 2000
4. Benmokrane et al. "Mechanical and Bond Properties of New Generation of ISOROD CFRP Reinforcing Bars for Concrete Structures", technical progress report, 2001, ISIS Canada
5. Market Development Alliance of the FRP Composite Industry (MDA) Website:
6. Gremel, D. "FRP Rebar - A State of the Industry Report Manufacturing, Construction, Economics and Marketing", Proceedings of the Workshop Composites in Construction: A Reality, 20-21 Jul., 2001, Anacapri, Italy.

REVIEWERS

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PUBLISHER

Emerging Construction Technologies, Division of Construction Engineering and Management, Purdue University, West Lafayette, Indiana