DURABILITY AND SERVICEABILITY OF FRP REINFORCED CONCRETE MEMBERS

ASHISH DABRAL,Department of Civil Engineering, Faculty of Technology,Uttarakhand Technical University, Dehradun, INDIA
ashishdabral44@gmail.com

ABSTRACT-

In this paper, we study on the mechanical and material properties of FRP bars, as well as on the main approaches used by the existing guidelines for the design of FRP RC structures. Study to present the ultimate limit state design principles for flexure at the basis of document CNR-DT 203/2006, going also into details of the reliability-based calibration of partial safety factors applied to assess the reliability levels of the Italian guidelines. In this paper, we are discussing the computational study on serviceability limit states flexural design of FRP RC elements. We have also explained the literature survey, properties of FRP bars, and finally, its applications.

Keywords-Fiber reinforced polymer, Reinforced concrete, Glass FRP, RC Bridge.

1. INTRODUCTION

Design Guidelines CNR-DT 203/2006, “Guide for the Design and Construction of Concrete Structures Reinforced with Fiber-Reinforced Polymer Bars”, have been lately developed under the auspices of the National Research Council (CNR). The new document (see front page in Figure 1) adds to the series of documents recently issued by the CNR on the structural use of fiber reinforced polymer (FRP) composites, started with the publication of CNR-DT 200/2004, pertaining to the use of externally bonded systems for strengthening concrete and masonry structures. The approach followed is that of the limit states semi-probabilistic method, like all the main current guidelines, while the format adopted is that of ‘principles’ and ‘practical rules’, in compliance with the classical style of Euro codes. It is also conceived with an informative and educational spirit, which is crucial for the dissemination, in the professional sphere, of the mechanical and technological knowledge needed for an aware and competent use of such materials. A guideline, by its nature, is not a binding regulation, but merely represents an aid for practitioners interested in the field of composites. Nevertheless, the responsibility of the operated choices remains with the designer. The document is the result of a remarkable joint effort of researchers from 7 Italian universities and practitioners involved in this emerging and promising field, of the technical managers of major production and application companies, and of the representatives of public and private companies that use FRP as reinforced concrete (RC) reinforcement (see Figure 2). Thus, the resulting FRP code naturally encompasses all the experience and knowledge gained in ten years of countless studies, researches and applications of FRP in Italy, joined to the learning gathered from the available international codes on the design of FRP RC structures. After its publication, the document n. 203/2006 was subject to a public hearing between February and May 2006. Following the public hearing, some modifications and/or integrations have been made to the document including corrections of typos, additions of subjects that had not been dealt with in the original version, and elimination of others deemed not to be relevant.

The updated document has been approved as a final version on 18/06/2007 by the “Advisory Committee on Technical Recommendation for Construction”.

The rest of the paper is organized as follows: Section II presents literature review. Section III describes properties of FRP bars. Section IV presents the forms of FRP reinforcement. Section V presents the typical applications. Finally, Section VI concludes the paper.

2. LITERATURE REVIEW

2.1 History of FRP Reinforcement

FRP composites are the latest version of the very old idea of making better composite material by combining two different materials (Nanni, 1999), that can be traced back to the use of straw as reinforcement in bricks used by ancient civilizations (e.g. Egyptians in 800).

The development of FRP reinforcement can be found in the expanded use of composites after World War II: the automotive industry first introduced composites in early 1950’s and since then many components of today’s vehicles are being made out of composites. The aerospace industry began to use FRP composites as lightweight material with acceptable strength and stiffness which reduced the weight of aircraft structures such as pressure vessels and containers. Today’s modern jets use large components made out of composites as they are less susceptible to fatigue than traditional metals. Other industries like naval, defense and sporting goods have used advanced composite materials on a widespread basis: pultrusion offered a fast and economical method of forming constant profile parts, and pultruded composites were being used to make golf clubs and fishing poles. Only in the 1960s, however, these materials were seriously considered for use as reinforcement in concrete. The expansion of the national highway system in the 1950s increased the need to provide year-round maintenance; it became common to apply deicing salts on highway bridges; as a result, reinforcing steel in these structures and those subject to marine salt experienced extensive corrosion, and thus became a major concern (almost 40% of the highway bridges in the US are structurally deficient or functionally no longer in use, ASCE Report card 2005).Various solutions were investigated, including galvanized coatings, electro-staticspray

fusion-bonded (powder resin) coatings, polymer-impregnated concrete, epoxy coatings, and glass FRP

(GFRP) reinforcing bars (ACI 440R.1R-06, 2006); yet the FRP reinforcing bar was not considered a viable solution and was not commercially available until the late 1970s.

In 1983, the first project funded by the U.S. Department of Transportation (USDOT) was on "Transfer of Composite Technology to Design and Construction of Bridges" (Plecnik and Ahmad 1988). Marshall-Vega Inc. led the initial development of GFRP reinforcing bars in the U.S. Initially, GFRP bars were considered a viable alternative to steel as reinforcement for polymer concrete due to the incompatibility of thermal expansion characteristics between polymer concrete and steel. In the late 1970s, International Grating Inc. entered the North American FRP reinforcement market. Marshall-Vega and International Grating led the research and development of FRP reinforcing bars into the 1980s. Parallel research was also being conducted on FRPs in Europe and Japan. In Europe, construction of the prestressed FRP Bridge in Germany in 1986 was the beginning of use of FRP (Meier 1992). The European BRITE/EURAM Project, "Fibre Composite Elements and Techniques as Nonmetallic Reinforcement," conducted extensive testing and analysis of the FRP materials from 1991 to 1996 (Taerwe 1997). More recently, EUROCRETE has headed the European effort with research and demonstration projects. In Japan more than 100 commercial projects involving FRP reinforcement were undertaken up to the mid-1990s (ACI Committee 440, 2001). The 1980s market demanded nonmetallic reinforcement for specific advanced technology; the largest demand for electrically nonconductive reinforcement was in facilities for MRI (Magnetic Resonance Imager) medical equipment. FRP reinforcement became the standard in this type of construction. Other uses developed as the advantages of FRP reinforcement became better known and desired, specifically in seawall construction, substation reactor bases, airport runways, and electronics laboratories (Brown and Bartholomew 1996).

3. PROPERTIES OF FRP BARS

The mechanical properties of FRP bars are typically quite different from those of steel bars and depend mainly on both matrix and fibers type, as well as on their volume fraction, but generally FRP bars have lower weight, lower Young's modulus but higher strength than steel. The most commonly available fiber types are the carbon (CFRP), the glass (GFRP) and the aramid (AFRP) fibers.

Table 1 lists some of the advantages and disadvantages of FRP reinforcement for concrete structures when compared with conventional steel reinforcement, as reported by ACI 440.1R-06.

The determination of both the geometrical and mechanical properties of FRP bars requires the use of specific procedures (ASTM D 618, ACI 440.3R-04). FRP bars have density ranging from one fifth to one forth than that of steel; the reduced weight eases the handling of FRP bars on the project site (ACI Committee 440, 2001). The tensile properties of FRP are what make them an attractive alternative to steel reinforcement. When loaded in tension, FRP bars do not exhibit any plastic behavior (yielding) before rupture. Therefore FRP reinforcement is not recommended for moment frames or zones where moment redistribution is required. Table 2 gives the most common tensile properties of reinforcing bars, in compliance with the values reported by ACI 440.1R-06. Figure 1 depicts the typical stress-strain behavior of FRP bars compared to that of steel bars. The CNR-DT 203-2006, instead, prescribes that all types of FRP bars can be used

provided that the characteristic strength is not lower than 400 MPa, and the average value of the Young's modulus of elasticity in the longitudinal direction is not lower than 100 GPa for CFRP bars, 35 GPa for GFRP bars, and 65 GPa for AFRP bars; the compressive modulus of elasticity of FRP reinforcing bars appears to be smaller thanits tensile modulus of elasticity, in fact most of FRP RC design guidelines suggest not to rely upon strength and stiffness contributions provided by the compressed FRP bars (further research is needed in this area).

The longitudinal coefficient of thermal expansion is dominated by fiber properties, while the transverse coefficient is dominated by the resin; typical values of the coefficient of thermal expansion in the longitudinal and transversal directions, αl and αt, respectively, of composite bars with a fibers volume fraction ranging between 50% and 70%, are reported in Table 3 (CNR-DT 203, 2006); higher values of the transversal coefficients of thermal expansion, combined with the Poisson's effect in the case of compressed reinforcements, can be responsible for circumferential tensile stresses that allow the formation of cracks in the radial direction that may endanger the concrete-FRP bond.

FRP reinforcing bars are susceptible to static fatigue phenomenon ("creep rupture"), which is a progressive reduction of strength under long term loads. In general, carbon fibers are the least susceptible to creep rupture, whereas aramid fibers are moderately susceptible, and the glass fibers are the most susceptible (ACI Committee 440, 2001); such phenomenon is also highly influenced by environmental factors, such as temperature and moisture. The bond between the FRP bar and the surrounding concrete is ensured by propagation of stresses whose values depend on bar geometry, chemical and physical characteristics of its surface as well as concrete compressive strength. The latter parameter is less important for FRP bars than for steel bars.

Table 1 - Advantages and Disadvantages of FRP Reinforcement

Advantages of FRP reinforcement	Disadvantages of FRP reinforcement
High longitudinal tensile strength (varies with sign and direction of loading relative to fibers)	No yielding before brittle rupture
Corrosion resistance (not dependent on a coating)	Low transverse strength (varies with sign and direction of loading relative to fibers)
Nonmagnetic	Low modulus of elasticity (varies with type of reinforcing fiber)
High fatigue endurance (varies with type of reinforcing fiber)	Susceptibility of damage to polymeric resins and fibers under ultraviolet radiation exposure
Lightweight (about 1/5 to 1/4 the density of steel)	Low durability of glass fibers in a moist environment
Low thermal and electric conductivity (for glass and	Low durability of some glass and aramid fibers in an

aramid fibers)	alkaline environment
	High coefficient of thermal expansion perpendicular to the fibers, relative to concrete
	May be susceptible to fire depending on matrix type and concrete cover thickness

Table 2 - Typical Tensile Properties of Reinforcing FRP Bars*

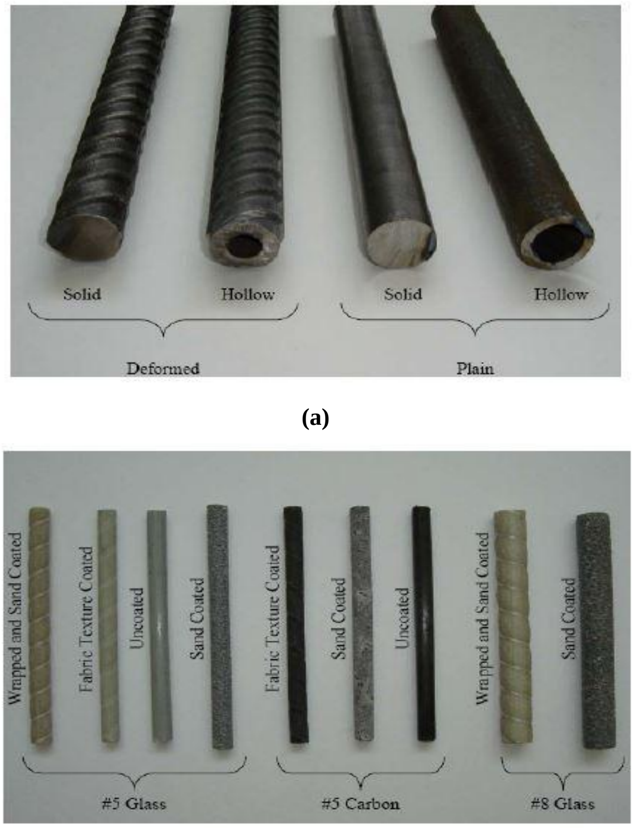
	Steel	GFRP	CFRP	AFRP
Nominal yield stress, MPa	276 to 517	N/A	N/A	N/A
Tensile strength, MPa	483 to 690	483 to 1600	600 to 3690	1720 to 2540
Elastic modulus, GPa	200	35 to 51	120 to 580	41 to 125
Yield strain, %	0.14 to 0.25	N/A	N/A	N/A
Rupture strain, %	6.0 to 12.0	1.2 to 3.1	0.5 to 1.7	1.9 to 4.4

Table 3 - Coefficients of Thermal Expansion

Bar	α1 [10-6 °C-1]	αt [10-6 °C-1]
AFRP	-6.0 ÷ -2.0	60.0 ÷ 80.0
CFRP	-2.0 ÷ 0.0	23.0 ÷ 32.0
GFRP	6.0 ÷ 10.0	21.0 ÷ 23.0

4. FORMS OF FRP REINFORCEMENT

Typical FRP reinforcement products are grids, bars, fabrics, and ropes. The bars have various types of cross-sectional shapes (square, round, solid, and hollow) and deformation systems (exterior wound fibers, sand coatings, and separately formed 20 deformations). A sample of different cross sectional shapes and deformation systems of FRP reinforcing bars is shown in Figure 2. One of the principle advantages of FRP reinforcement is the ability to configure the reinforcement to meet specific performance and design objectives. For example, FRP reinforcement may be configured in rods, bars, plates, and strands. Within these categories, the surface texture of the FRP reinforcement may be modified to increase or decrease the bond with the surrounding concrete. Unlike conventional steel reinforcement, there are no standardized shapes, surface configurations, fiber orientation, constituent materials and proportions for the final products. Similarly, there is no standardization of the methods of production, e.g., braiding, filament winding, or FRP preparation for a specific application.



(a)

(b)

Figure 1 (a) & (b): Sample FRP Reinforcement Configurations.

5. TYPICAL APPLICATIONS

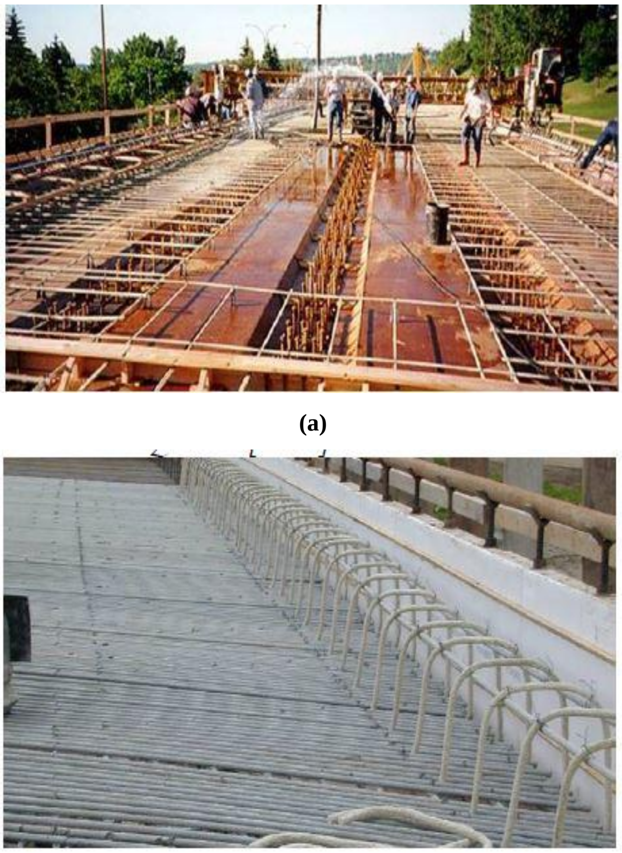
The use of FRP in concrete for anti-corrosion purposes is expected to find applications in structures in or near marine environments, in or near the ground, in chemical and other industrial plants, in places where good quality concrete cannot be achieved and in thin structural elements. Most initial applications of FRP reinforcement in concrete were built in Japan, where many demonstration projects were developed in the early 90's, like floating marine structures

In North America, Canada is currently the Country leader in the use of FRP bars, mainly as reinforcement of RC bridge decks (Benmokrane, Desgagne, and Lackey 2004); Figure 3 and Figure 4 show some recent bridge applications in USA and Canada (the corresponding reference has been reported when available).

(a)

(b)

Figure 2 (a) & (b): Recent Applications of FRP RC Bridge Decks in USA (Source: GFRP Bridge Deck, Morristown – Vermont (USA), 2002).



(a)

(b)

Figure 3 (a) & (b): Recent Applications of FRP RC Bridge Decks in Canada (Source: Crowchild Bridge Deck, Calgary, Alberta Rizkalla, 1997).

6. CONCLUSION

This paper presented a review study of FRP reinforcement. In this paper we discussed the ultimate limit states design, both for flexure and shear. Further, serviceability limit states design, specifically the deflection control. In future, we will do the test methods for characterizing FRP bars.

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