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GFRP REINFORCEMENT IN CONCRETE – FACTORS AFFECTING BOND PROPERTIES

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Abstract: *Corrosion of steel reinforcement is the major cause of deterioration of existing RC structures. Combined effects of moisture, temperature, and chlorides reduce the alkalinity of concrete and exacerbate the corrosion of steel reinforcement, especially for concrete structures subjected to aggressive environments, such as marine structures and bridges and parking garages exposed to de-icing salts. Glass fiber reinforcement polymer (GFRP) bars are suitable alternatives to steel bars in reinforced concrete applications if durability, electromagnetic transparency, or ease of demolition in temporary constructions is sought, that have to be demolished partially by tunnel boring machines (TBMs). The bond of GFRP reinforcement is different from steel reinforcing bars. This paper presents factors affecting the bond strength between GFRP reinforcement and concrete.*

Keywords: Concrete, GFRP reinforcement, Bond, Temperature, Environmental conditions.

1. Introduction

It is known that, in well designed and quality concrete have high alkalinity of the concrete pore solution. At this high pH, the embedded reinforcing steel is protected against corrosion due to the formation of a sub-microscopically thin film. With time, the alkalinity becomes reduced in the concrete due to chemical reactions (Karlsson, 2014). A significant number of existing structures (buildings, bridges, park decks etc.) need strengthening, rehabilitation or replacement. Corrosion produces deep pitting and severe loss of cross section of the reinforcing steel. This normally leads to costly repair and catastrophic failures. Several approaches have been chosen to control the corrosion process such as improving the permeability of concrete by additives and admixtures and epoxy-coating steel bars. The latter has been widely used in bridges and parking garages. A completely different approach to control the corrosion process would be to use materials that are highly corrosion resistant, such as reinforcing bars constructed of composites materials. Glass fiber reinforced polymer (GFRP) bars (Fig. 1) that have been produced recently are considered to be ideal candidate and have great potential to fill such a need. While glass fibers are highly resistant to corrosion by acids, the combination of wrongly types of glass fibers and resins could lead to premature deterioration of GFRP bars in alkaline environment. However, many structures constructed with these bars have been in service for more than ten years in extremely aggressive environments (Eshani et al, 1996).

Fig. 1: Composite GFRP reinforcement.

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The use of polymer composite materials instead of steel can be considered as a promising alternative. Glass fibers are a popular choice as reinforcement due to their low cost and many advantageous features. The advantages of GFRP include high strength, low density, and low cost. However, the relatively low elastic modulus of GFRP bars (compared with that of steel) generally leads to a higher deformability and greater crack widths in GFRP-reinforced structural elements. The design and construction guidelines for the use of GFRP bars are in many ways based on knowledge gained from steel reinforcement design (Karlsson, 2014).

2. Bond behavior of GFRP bars

Bond between reinforcement and concrete is necessary to ensure composite action of the two materials. The force in the steel bar is transmitted to the surrounding concrete by bond, which can be divided into three components: adhesion, mechanical interlocking and friction. The understanding of bond behavior of GFRP bars is important because most bond behavior models for studying the bond of GFRP bars have evolved from models that were previously developed for steel bars. Because these models for steel bars are well-established, they serve as convenient data to define the bond behavior of GFRP bars (Ganga et al. 2012). Generally, the resin used for the production of the bars is water resistant and therefore the formation of chemical bonds between the concrete and the bar is very limited unless special treatment is used. Results from experimental research have shown that there are two bond components for GFRP bars: mechanical interlocking and friction due to surface roughness (Zhou et al, 2012).

Trends in the literature have also shown that the average bond strength of GFRP bars is approximately 55 to 90 percent of steel reinforcement of the same diameter (Vint, 2012). Despite some research has been done in the evaluation of the bond behavior of FRP bar in concrete during the last decades, there is not yet a formulation that has a large acceptation of the technical and scientific communities for the prediction of the bond behavior between GFRP bars and surrounding concrete (Mazaheripour et al., 2013). Typical surface profiles used in GFRP bars to improve bond interaction include: sand coating, helical or braided wrapping with fibers to created indentations in the bar's surface, and deformations in the resin (surface indentations or ribs). The average bond strength is higher for bars that are ribbed or have helical strands wrapped around them than for bars that are purely sand coated (Fig. 2) (Vint, 2012).

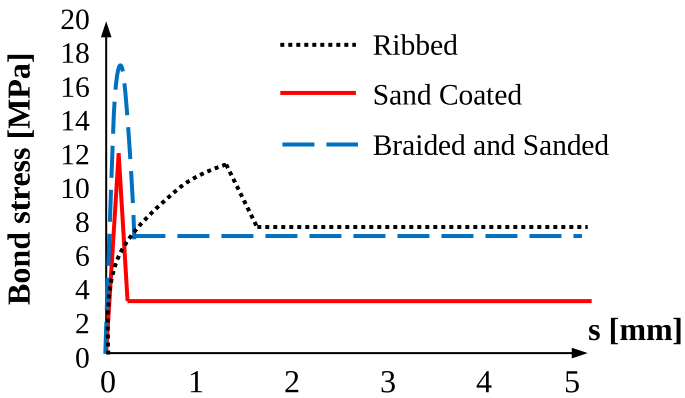

Fig. 2: Bond stress-slip relationship for GFRP bars with different surface (Vint, 2012).

2.1. Effect of different environmental conditions

Information from durability tests and life cycle analysis has to be established for the tested FRP reinforcement to determine the bond strength modification factor k_D, which should be related to environment and time. If the modification is in the code in form of a reduction of tensile strength of FRP, then a reduction of bond strength should not be necessary. If GFRP is used for the civil structures, the influence of water on the durability of GFRP is a critical issue since the civil structures are usually exposed to moisture during their service life. The influences of various environments such as moisture, alkali and chloride solutions, and wetting and drying cycles on the durability performance of GFRP composites have been investigated by numerous researchers. However, few long-term performance data are available for GFRP composites to date. Therefore, the durability performance of GFRP has been an important issue in recent years. Generally, an accelerated aging method with high temperature was used to accelerate the degradation process of GFRP (Kim et al., 2006).

The ACI 440.1R guide for internal GFRP reinforcement recommended an environmental reduction factor k_D, to represent the reduction in strength and strain properties of GFRP materials during their service life (Tab. 1). The environmental reduction factor k_D depends on the location and severity of exposure conditions. For GFRP the k_D varies from 0.75 to 0.50. Reduction factors are higher for external exposure conditions such as bridge decks, beams, and columns. Lower reduction factors are suggested for interior exposure conditions such as building beams and slabs because of the reduced severity and exposure to environmental elements (e.g., moisture, temperature fluctuations, and others) Ganga et al. 2012).

Tab. 1: Environmental reduction factor for GFRP bars at different exposure conditions (Ganga, 2012).

Exposure conditions	**Environmental reductions factor (k_D)**
Interior exposure	0.75
Exterior exposure (bridges, piers and unclosed parking garages)	0.65
Aggressive environment (chemical plants, waste water treatment plants)	0.50

2.2. Bond properties at elevated temperature

The bond between GFRP and concrete is essential to transfer loads. In the event of fire, changes in the mechanical properties of the matrix have the potential to cause loss of bond at modestly increased temperatures, and result in loss of interaction between FRP and concrete. The result could be catastrophic.

Tab. 2: Bond between GFRP bars and concrete at elevated temperature (Tepfers, 2004).

Temperature (°C)	**Bond strength in % of values at 20°C**	**k_T (-)**
20	100	1.0
100	35 - 80	0.35 - 0.8
150	20 - 40	0.2 - 0.4
220	10 - 20	0.1 - 0.2

GFRP bars at elevated temperatures may experience significant transverse thermal expansion leading to cracking or spalling of the concrete cover or to the development of shear stresses in their adhesive layer. They may ignite and emit dense smoke and toxic gases. They can lose their bond with the substrate or surrounding concrete. All of these concerns have not been adequately studied or addressed by current design guidelines (Bisby et al., 2005). The use of GFRP reinforcement is not recommended for structures in which fire resistance is essential to maintain structural integrity. Because FRP reinforcement is embedded in concrete, the reinforcement cannot burn due to a lack of oxygen; however, the polymers will soften due to the excessive heat. The temperature at which a polymer will soften is known as the glass-transition temperature Tg. Beyond the Tg, the elastic modulus of a polymer is significantly reduced due to changes in its molecular structure. The value of Tg depends on the type of resin, but is normally in the region of 65 to 120 °C (ACI, 2006). Below zero temperatures can cause changes in mechanical properties and create additional micro cracks in GFRP materials (Mathieu et al., 2010).

3. Design bond stress for reinforcing bars

The design value of the ultimate bond stress fbd for GFRP reinforcing bars may be taken as (Tepfers, 2004):

$$f_{bd} = \eta_0.\eta_1.\eta_2.k_D.k_T.f_{ctd} < f_{bd,FRP} \qquad (1)$$

where:

- η_0 is a coefficient related to the structure of the surface of the reinforcing bar. η_0 = 2.25 for ribbed steel bars, for GFRP shall be defined by manufacturer for every type of GFRP rebar,

- η_1 is the coefficient related to the quality of the bond condition and the position of the bar during concreting according to STN EN 1992-1-1,

- η_2 is related to the bar diameter: η_2= 1.0 for Ø ≤ 32 mm, η_2= (132- Ø)/100 for Ø > 32 mm,

- k_D is modification factor for durability (see Tab. 1),

- k_T is modification factor for temperature (see Tab. 2),

- f_{ctd} is the design value of concrete tensile strength (= $f_{ctk,min}/\gamma_C$),

- $f_{bd,FRP}$ is the design bond strength in the surface of the FRP-bar/rod (determined in pull-out test with short bond length and central placement of bar/rod).

4. Summary

For GFRP an extensive experimental work is needed in order to develop reliable and rational guidelines for design. One property of importance that has been studied for many years is the bond between steel reinforcing bars and the concrete interface. This property is crucial, as it has a major effect on the structural performance of a member with regards to cracking, deformability, internal damping and instability in concrete structures. It is critical that the bond interface does not deteriorate, thereby ensuring an adequate level of strength and ductility in the structure. While the bond characteristics of steel bars in concrete have been investigated extensively, such data are lacking for GFRP bars. It cannot be assumed similar responses for steel and GFRP bars due to their different mechanical and physical properties.

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