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Report on Concrete Structures Reinforced with FRP Bar

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Abstract:

Fiber reinforced polymer (FRP) bars have been widely used in civil engineering used as a substitute for steel reinforcement because it has many advantages such ashigh strength-to-weight ratio, electromagnetic neutrality, light weight, ease of handling and no corrosion. Moreover, the productive technology becomes more and more mature and industrialized so that FRP has become one economic and competitive structure material. Based on the recent researches, this paper mainly introduces progress in the studies on concrete structures reinforced with FRP bars. These contents in this paper includes the bond performance of FRP bars in concrete, Compression Behavior, flexural behavior, and ductility of concrete structure reinforced with FRP bars in the past few years in the world.

Key words:

FRP Bars, Concrete Structure, Bond Performance, Pullout Behavior, Compression Behavior, Flexural Behavior, and Ductility.

Introduction

Infrastructure decay due to corrosion of embedded reinforcing steel stands out as a significant challenge worldwide [1]. The use of FRP bars as reinforcement for concrete elements seems to be an effective solution for overcoming durability problems of traditional steel reinforced concrete structures due to the corrosion of metallic bars. For this reason, the replacement of steel with FRP bars is gaining popularity worldwide [2]. It has many advantages such as high strength-to-weight ratio, electromagnetic neutrality, lightweight, ease of handling, no corrosion, low weight to strength ratio (1/5 to 1/4 times of the density of steel), high longitudinal tensile strength, and non-magnetic characteristics. Although the initial cost of FRP reinforcement is higher than steel reinforcement, the total life cycle cost of the structure or structural components reinforced with FRP is lower, as significantly less maintenance costs are required for structures or structural components reinforced with FRP [3]. The application of FRP bars in civil engineering can be divided into two classes. One is to substitute steel bars in concrete structures, and the other one is to maintain and strengthen old structures. In the past few years, with the development of FRP material technique, more and more scholar began to focus on the application research work on FRP. This paper mainly introduces progress in the studies on concrete structures reinforced with FRP bars.

These contents in this paper include the bond performance of FRP bars in concrete, shear resistance, flexural behavior, compressive behaviour and ductility of concrete structure reinforced with FRP bars in the past few years in the world.

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Bond strength and its factors: – The mechanics of bond stress transfer between FRP reinforcement and concrete has been investigated extensively. Bond stress is the shearing stress whose direction is parallel to the interface plane of FRP bars and concrete. The bond of an embedded bar, regardless of material, resists pull-out via three main mechanisms. The first is chemical adhesion between the two materials at their interface. The second is the friction bond which is due to coarseness in the surface of the bar. The third mechanism contributing towards the bond is mechanical bearing, such as that generated from the lugs on reinforcing bars upon the surrounding concrete[4].

Based on the studies on concrete reinforced with FRP bars, the factors that influence the bond strength can be divided to several classes below:

The bond performance of FRP bars in concrete, which is the basic mechanical behavior, is the main factor of the mechanical performance, failure mode, serviceability, crack width, deformation and structure analyses and design.

Pullout behavior of FRP bar with different strength of concrete

The bond performance of 88 concrete pull-out specimens prepared according to ACI 440.3R-04 and CSA S806-02 standards with FRP bars were investigated by Baena et. al. [5]. Rebars (reinforcing bars) made of carbon-fibre and glass-fibre reinforced polymer (CFRP and GFRP), as well as steel rebars, with a constant embedment length of five times the rebar diameter were used. The influence of the rebar surface, rebar diameter and concrete strength on the bond–slip curves obtained is analyzed. Hence, an average bond stress is defined ? = P/ ? db lb where P is the tensile load, db is the rebar diameter, and lb is the embedment length. In his experiment, different strength of concrete was adopted. The experimental results confirm the tendency of rebars with larger diameters to have lower bond strength, especially in the case of higher strength concrete (M60). Pull-out test of normal-strength concrete and high-strength concrete were performed by Chaallal and Benmokrane [6]. The experimental bond strength results from pullout tests performed on GFRP rods embedded in NSC (Normal strength concrete) varied from 11.1 to 15.1 MPa with an overall average of 12.9 MPa. For the sake of comparison, pullout tests were performed on conventional deformed steel rebars using the same NSC overall average of 18 MPa. GFP rod bond strengths associated with HSC (high strength concrete) varied from 8.4 to 15.8 MPa, with an overall average of 12.1 MPa. For the sake of comparison, pullout tests were performed on conventional deformed steel rebars using the same HSC overall average of 30 MPa (which is 62% to 84% of that of steel deformed bars). Veljkovic et. al. [7] found in his experiment that the Ribbed GFRP bars develop bond strength differently according to concrete mechanical properties. Concretes with average compressive strength in range 25-40 MPa do not influence strongly the bond strength, while within range of 40-65 MPa, bond strength is enhancing significantly.

Highest concrete strength delays onset of cracking in low covers, but allows smoother and faster crack advancement. Veljkovic et. al. [7] also uses DIC (Digital Image Correlation) technique for recording and evaluating of strain field of the specimens.

Results shows that the both types of GFRP bars presented comparable, but still, in average, lower bond strength compared to steel ones under the same experimental conditions but the use of thin concrete cover (10 mm in this case) in combination with ribbed GFRP bars attained similar bond strength as steel bars and showed the real advantage of use of this GFRP bars instead of standard steel ones. Golafshani et al. [8] did extensive research on bond behavior of steel and GFRP bars in normal concrete (NC) and self-compacting concrete (SCC) of 104 pullout specimens. The results revealed that the bond behavior of GFRP bars in SCC shows better results as compared to the GFRP bars used in NC. This is due to the superior filling capacity of SCC compared to NC. However, the bond strength variations of steel bars are less than that of GFRP bars.

Flexural behavior of Reinforced concrete beams with FRP bars

Several experimental studies were conducted to investigate the flexural behavior of FRP reinforced concrete beams and comparison with that of steel reinforced concrete beams. Rafi et. al. [9] investigated flexural behavior of CFRP (Carbon fiber reinforced polymer) reinforcement RC beams and normal RC beams and compared the results of both. Test results show that the structural behaviors of CFRP reinforced concrete are similar to normal RC in many aspects. The CFRP RC beams displayed good bond between the reinforcement bars and concrete, with no signs of bond failure or slip. Beams failed due to concrete crushing at almost double the loads on the other hand steel RC beams failed due to steel yielding. The long-term flexural behaviors of a hybrid system consisted of continuous fiber-reinforced-polymer (FRP) rebar and fiber- reinforced-concrete (FRC) were investigated by the Wang and Belarbi [10], and the results shows that the ultimate flexural strength experienced minor reduction when exposed to combined environmental conditioning, including freeze–thaw cycles, high temperature (60°C), and de-icing salt solution. The degradation of concrete may be the main reason for the flexural strength degradation. The behaviour of GFRP (Glass fiber reinforced polymer) RC beams with different percentages of reinforcement ratio and concrete strengths under static and impact loading were investigated by the Goldston et. al. [3], the results reveals that the six GFRP RC beams were tested under static loading and the remaining six GFRP RC beams were tested under impact loading (using a drop hammer). To examine the failure modes and associated energy absorption capacities. Author reported that the 15- 20% higher dynamic moment capacities compared to static moment capacities and Reinforcement ratio and the strength of concrete influenced the behaviour of GFRP RC beams. Escorcio and Franca [18] presented a rehabilitation solution to replace the tension steel reinforcement of a RC beam with GFRP bars, which is a material immune to corrosion. As per the author observation that the rehabilitated beams with GFRP bars exhibited a bilinear behaviour until failure in terms of load-deflection as expected since the ductile performance of the reference beam with steel reinforcement is not possible to replicate due to the GFRP material linear elastic property until failure. An

experimental study was conducted by Hosen et. al. [11] to investigate the performance of RC beams strengthened with SNSM (side near-surface mounted)-GFRP (Glass fiber reinforced polymer) bars. The results of this study showed that the Strengthening using SNSM (side near-surface mounted) -GFRP bars enhanced the first crack and ultimate loads up to 4.38 and 1.55 times compared with the control specimen. The use of GFRP as

an SNSM reinforcement has exhibited a tri-linear response in load-deflection behavior and reduced the deflection at any load level of the specimens, which would address the serviceability concerns.

Compressive behavior of Reinforced Concrete columns with FRP bars

Few experimental studies were conducted to investigate the influence of replacing steel bars with GFRP bars on the behaviour of square and circular concrete columns. H. Karim et. al. [12] investigated the behaviour of concrete columns reinforced with FRP bars. A total of five circular concrete columns of 205 mm in diameter and 800 mm in height were cast and tested under axial compression. The specimens were reinforced either with GFRP bars and GFRP helices or only with GFRP helices. The experimental results showed that the GFRP-RC columns experienced two peak axial loads. The first peak load represents the maximum load carrying capacity of the gross concrete cross-section (concrete core and cover). The second peak load represents the maximum load carrying capacity of the concrete core confined by the FRP helices. M.Z. Afifi et. [13] also presented tests that were performed to investigate the axial compression behavior of circular concrete columns reinforced longitudinally with GFRP bars and transversely with newly developed GFRP spirals. A total of 12 full-scale RC columns were prepared to study five test variables: reinforcement type (GFRP versus steel); longitudinal FRP reinforcement ratio; and different volumetric ratios, diameters, and spacing of spiral reinforcement. The test results indicated that the GFRP and steel RC columns behaved in a similar manner. The average load carried by the longitudinal GFRP bars ranged between 5% and 10% of the maximum load. The test observations also indicated that failure of the GFRP RC columns with large spiral spacing or with small volumetric ratio (0.7%) was controlled by longitudinal bar buckling. Conversely, failure of the well- confined GFRP RC columns was attributed to the crushing of the concrete core and rupture of the GFRP spirals. The experiments were conducted to investigate the behavior of glass fiber reinforced polymer reinforced concrete columns (GFRP-RCCs) under an eccentric axial load by L. Sun et. al. [14]. Nine short columns (L/h = 4) were cast: three each with initial eccentricities of 175 mm, 125 mm, and 75 mm. The test results showed that the steel reinforced concrete columns fails in terms of steel yielding behavior on the other hand GFRP- RCCs experienced pressure-side concrete crushing failures. However, the glass fiber reinforced polymer (GFRP) bars in the concrete columns mostly remained intact after the concrete was crushed. Therefore the load-deformation curves of eccentrically loaded GFRPRCCs are on an overall basis different from regular steel reinforced concrete columns in terms of yielding behavior, and thus damage is expected immediately after ultimate load is reached, and they exhibit brittle characteristics. Glass fiber reinforced plastic (GFRP) was used to reinforce concrete columns that were

experimentally investigated under compression loading to assess structural behavior and performance by W. Prachasaree et. al. [15] specimens were prepared with varied longitudinal reinforcement, concrete cover, and lateral reinforcement. Based on this study, the amount of GFRP longitudinal and lateral reinforcement slightly affected the column strengths. While different types of lateral enforcement had little difference in strength, the spiral lateral reinforcement was the most effective in terms of the confining pressure and the inelastic deformation.

Durability of FRP bars under different temperature in Concrete

Galati et al. [2] perform an experimental investigation was carried out on concrete specimens reinforced with a FRP bar and subjected to thermal cycles with a maximum temperature value of 70°C and Galati et. al. [2] also observed that the most of the specimens the thermal treatment induced a slight degradation in the bond performance in terms of ultimate load and more extended micro cracking of the concrete (due to the different CTE (coefficient thermal expansion)) of GFRP bars and concrete when the bars are placed at a lower cover. Robert and Benmokrane [11] also accomplish an experimental investigation of the durability of the bond between GFRP bars and concrete. The GFRP bars were embedded in concrete and exposed to tap water at (23°C, 40°C and 50°C) to accelerate potential degradation. Robert and Benmokrane [11] were also use Fourier transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), and scharacterize how bar aging affected the bond between the GFRP bars and the concrete. Results demonstrations that aging did not significantly affect the durability of the bar–concrete interface underthe conditions used in this study.

Role of Ductility in FRP reinforced concrete structures

The ductility and confinement efficiency can be better improved by using small GFRP spirals with closer spacing rather than larger diameters with greater spacing. Ignoring the contribution of GFRP bars in the design equation underestimated the maximum capacity of the tested specimens. Sun et al. [3] observed that the GFRP bars can play a specific role in improving ductility for large-eccentricity specimens while this effect is weak or insignificant with respect to small- eccentricity specimens. In the descending section of the load-deformation curve, the ductility of the GFRP reinforced concrete columns increased with increases in eccentricity. Therefore, it is recommended by the author that the configuration of stirrups in GFRP-RCCs should be strengthened when they are used in a small eccentric compression environment to improve ductility. Wang and Belarbi [10] investigate that the concrete properties was improved by adding fibers with a volume fraction of 0.5% has been proved to be an effective way to enhance the ductility of FRP reinforced system. When compared to the companion plain concrete beams, the FRC beams showed more than 30% increase in the ductility index for both unweathered and weathered.

Role of Stiffness in FRP reinforced concrete structures

Stiffness is defined as the capability to prevent bending or deflection of the specimens under loading. It is one of the most important characteristics of the RC structures under serviceability behavior. The SNSM-GFRP-strengthened specimens resulted in higher stiffness compared with the control specimen observed by Hosen et.al [11]. Test results revealed that the increasing the size of GFRP bars from 8 to 10 mm Ø increased the stiffness from 100% to 114% compared with the control specimen. Moreover, the increase in the bond length from 1600 mm to 1900 mm improved the stiffness by 35% and 15%, respectively, for 8-mm Ø to 10-mm Ø GFRP bars. In this study, the stiffness of the strengthened specimens mostly depended on the size of the SNSM bars. Baena et. al. [5] also observed that there is a high level of stiffness with no slip in the steel rebars, whereas the FRP rebars develop slip from the beginning (The slip values obtained for GFRP are greater than those for CFRP bars). The experimental results also confirm the tendency of rebars with larger diameters to have lower bond strength, especially in the case of higher grade of concrete.

Role of economy while using FRP reinforced concrete structures

Researcher all over the world are focusing on the use of GFRP bars in concrete structures owing to their advantages in comparison to normal reinforcing steel. Berg et. al. [16] presented a study of the bridge is almost entirely reinforced with GFRP, with a small amount of steel used also. Although the initial material cost for the GFRP reinforced deck was 60% higher than the steel reinforced deck the construction time for the GFRP deck was considerably faster than the steel deck. The rate of concrete placement on the GFRP reinforced bridge deck was 51.15m3 per hour compared to 29.05 m3 per hour for the steel reinforced deck. This shows that the GFRP deck was able to reduce construction costs by 57% compared to steel. Additionally to that long term cost savings due to decreased need for maintenance works or increased service life of the bridge deck. Long term monitoring of this bridge and its twin will be conducted to determine comparisons between the long term behavior of both GFRP and steel reinforced bridge decks.

El Salakawy et. al. [17] presented a study of Wotton Bridge, in Quebec, Canada, is essentially a full-scale long term test comparing the performance of GFRP reinforcing bars to conventional steel reinforcing bars. Test results showed that the FRP portion of the bridge deck behaved very well. Author observed that the deflections were well within the limits set by the Canadian code and maximum recorded strains for the static truck loading were only 0.13% of the ultimate for FRP and just 4% for the service load over one year. Strain values in the concrete due to truck loads were significantly lower than the predicted cracking strain. Ongoing test data will be valuable to allow direct comparison between steel and FRP reinforced bridge decks.

Summary

With 20 years' studies on the mechanical behaviors of FRP bars RC structure, great progress has been made, and lots of design codes have been published worldwide. The corrosion of steel reinforcement in concrete and the resulting deterioration of structures prompted research on FRPs as potential reinforcement for concrete. State of art in research indicate that FRP reinforcement can be effectively used in beams and column in new concrete structural elements. There has been a significant progress in understanding the behaviour of FRP (GFRP mostly) bars in concrete but, the focus of most of these studies has been the modification in the flexural and shear strength capacities of concrete beams reinforced with FRP bars. The effectiveness of FRP reinforcement as main reinforcement and hoops steel in columns has also been

reported. The level of understanding of structural behavior has reached a stage where several codes and design guidelines have been issued and developed around the world. FRP bars as reinforcement improve the flexure and shear behaviour but the analysis of onset and progression of cracking in FRP reinforced concrete beams by the complementary use of NDT techniques for the characterization of mechanical performance is still untouched. Therefore, studies are still needed to be investigated on the FRP bars RC structures, especially bond behaviors, flexural behaviour and compressive behaviour.

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