SHEAR PERFORMANCE OF GFRP BARS EMBEDDED IN CONCRETE BEAMS WITH CRACK IN DIFFERENT ENVIRONMENTS

Wen-rui Yang, Xiong-jun He, Li Dai

School of transportation, Wuhan University of technology, Wuhan 430063, China
Email: wryang99@163.com, hxjwhut@163.com, dlwhut2012@163.com

Keywords: GFRP bars, Concrete beam, Interfacial fracture energy, Work crack, Alkaline environment

ABSTRACT

An experimental and analytical investigation of shear performance of glass fiber-reinforced polymer (GFRP) bars embedded in concrete beams with crack is presented. Beams were conditioned with sustained flexural loads in outdoor, 60°C alkaline solution, and tap water environments for 90 days, 180 days and up to 270 days, after which they were subjected to eccentric three-point flexure tests to evaluate shear performance. The obtained ultimate load retention rate, deformation deflection and the load versus crack mouth opening displacement curves (P-CMOD) were used to analyze the influence rule of crack on shear performance in different environments. Results show that the maximum difference of the ultimate load retention rate and deformation deflection values can respectively reached to 38.5% and 46.3% in different environments. The obvious deterioration influence of alkaline environment on the shear performance of GFRP reinforced concrete beam has already been proved, however, the environmental impact was intensified by crack on the shear performance of GFRP reinforced concrete beams.

1 INTRODUCTION

Long-term performance of GFRP reinforced concrete research was focused on by researchers, and the GFRP reinforced concrete structure of the overall shear performance is worthy to study because of the shear capacity of poor GFRP bar. Concrete structures often have different degrees of cracks and flaws and the channels for the external environment medium erosion into the internal are provided by cracks, leading to a certain damage for internal structure. The evaluation of FRP reinforcement concrete structure will be no longer completely effective and reliable through the traditional strength theory, which does not consider the effects of cracks[1].

Xiong-jun He et al.(2014)[2][3] researched the long-term tensile strength of GFRP bars embedded in concrete beams with initial cracks, and the influence of the experimental results showed the different degree degeneration effect on crack load, sliding load, deflection deformation and slip of GFRP reinforcement concrete with initial cracks in the same environment, with including the highest loss of sliding load values can amount to above 40% and the bond stress losses as high as 59.4% when GFRP bars embedded in concrete beams with initial cracks in alkaline environment for 270 days. Visible, the influence of cracks on durability performance of GFRP reinforcement concrete structure should not be neglected, it is necessary to make an intensive study on mechanical performance of FRP reinforcement concrete beams with cracks, however, this aspect of the work is still very limited[4][5].

According to the actual state of concrete beam subjected to load with work cracks, GFRP reinforced concrete beams with different pre-crack width will be subjected to accelerated aging durability tests and eccentric three-point shear tests. Contrastive analysis the crack failure forms,
ultimate load retention rate and the deflection values of beams with crack compare to those without crack, and summarize the influence of cracks on the shear performance of GFRP reinforcement concrete beam in different environments.

2 EXPERIMENTAL

2.1 Materials and Specimens Fabricating

The GFRP bars used in this investigation were provided from Feng-hui composite material co., ltd, Nanjing in China, which have a helical indent formed and a light coating of sand. The equivalent diameter of the bar is measured 10 mm by the writers using the immersion method, and the mean value of tensile strength was 1087.64 MPa by the tensile tests of four GFRP bars. The tensile test of GFRP bars according to the relevant requirements of ACI440.3R-04 B2 were proceed in SHT4106-G type microcomputer control electro-hydraulic servo universal testing machine. In order to prevent the shear failure on the both ends of GFRP bars, a 250 mm long steel pipe anchorage was fixed on the GFRP bars ends. Load values were recorded by sensor automatic with the 2 mm/min loading rate.

Typical two methods for investigating the durability performance of GFRP bars embedded in concrete involve conditioning bars in aggressive environments either before (Katsuki and Uomoto. 2007) or after (Robert, Cousin and Benmokrane. 2009) casting bars in concrete blocks. However, from the practical application and experimental studies shows, traditional alkaline solution simulation test results of concrete pore water cannot be directly equal to the actual situation of the reinforcement in concrete; the existing design specifications of GFRP reinforcement may be conservative.

The GFRP bar configured in rectangular section concrete beam with crack was specialized to explore the fracture performance in alkaline environment and sustained loading. According to “Specification for mix proportion design of concrete” made concrete beams, with 28 days target strength of 30 MPa. The beams were 80 mm wide, 110 mm deep and 1,100 mm long. For simplicity to interpret the results and the fracture performance, beams used in the research had a single longitudinal GFRP bar centered 30 mm from the bottom of the section by considering the inclined section damage factor relatively concentrated on the no shear reinforcement beam.

2.2 Prefabricated work crack and Environmental Conditioning

Preliminary four-point flexure tests were done to determine the ultimate bending moment of the beams and provided the original design data for pre-cracked load. A pair of GFRP bars embedded in concrete beams did not prefabricate work crack as for reference, the rest of beams were pre-cracked by four-point flexure tests after achieving age.

The homemade counterforce frame between steel frame and steel spring was used to apply flexural loads and to produce stable crack, and spring coefficient is 40kN/mm (Figure 1). The inner two load points were located 250 mm from the outer load points, while the two outer load points were located 50 mm inward from the ends of the beam. Failure of four-point flexure tests occurred in a shear/compression mode at one of the inner load points at a mean applied moment of 0.8kN·m. According to the guide ACI440.1 R-06 calculation and the experimental verification to determine pre-crack bending moment was 50% of ultimate bending moment, Simulated concrete beams under the sustained loading working state, the bending moment decreased to 20% of the ultimate bearing
capacity after generated stable crack, load should be avoid concrete continuous beam of creep rupture (ACI Committee 440, 2004)[6]. The compressions of steel spiral springs were periodically monitored to make the cross section bending moment within the given range of error.

![Homemade counterforce frame](image1.png)

**Figure.1. Homemade counterforce frame**

In order to make a contrast analysis of the fracture performance of GFRP reinforced concrete beam with cracks under different environments and sustained loading, beams conditioned in the three testing environments outdoor, tap water, and 60℃ alkaline solution.

A group of beams conditioned in the local unsheltered outdoor environment were loaded for 9 months. The experimental were scheduled to start in November and end dates in July for the outdoor beams so that all beams experienced at least one winter period and one summer period. In the laboratory of Wuhan University of Technology, Wuhan in China, the mean annual temperature is 16.4℃, the mean daily high temperature is 42℃ in the summer, the mean daily low temperature is -3℃ in the winter, and the mean annual precipitation is 1.30 m (China's meteorological nets)[13]. A group of beams conditioned in the tap water environment were loaded for 9 months at a temperature of 23±3℃. A group of beams conditioned in the alkaline environment consisted of 60±2℃ tap water saturated with (pH = 13.5). Loads were applied in 60℃ alkaline solution environment for 9 months[12]. It is necessary to set up two groups of beams with pre-crack and without pre-crack to highlight the influence of crack on fracture properties of GFRP reinforced concrete beam, four beams were conditioned in each environment for each condition. After the accelerated corrosion, the beams were unloaded for eccentric three-point flexure tests.

### 2.3 Shear test

An eccentric three-point shear test was conducted to evaluate fracture performance of GFRP bars embedded in beams environmentally conditioned with crack. Five strain gauges, the fracture mechanics clip-on gages and the displacement gauge were fixed on beams as Figure 2. A reaction frame and hydraulic jack was specialized to carry out the eccentric three-point flexure tests, and a data acquisition system synchronization was used to record the load value, the strain value, the crack mouth opening displacement and the mid-span displacement, at the meantime, the camera was used to observe and record the development of cracks.

![Three-point flexure test](image2.png)

**Figure.2. Three-point flexure test (unit: mm)**

### 3 RESULTS AND DISCUSSION
3.1 Failure pattern and Crack propagation

In roughly 90% of the test, the failure pattern in eccentric three-point flexure was in line with the shear failure modes, and one primary crack always occurred near the load point, followed in many cases by crack branching and additional shear cracks in the anchorage zone. In the early stage of the load, the pre-crack extended with loading, longitudinal cracks began to appear at the bottom of the beam until load applied to 2-3kN, however, the primary crack of beams without pre-crack was emerged with the load of 3-4kN. The occurrence time of primary crack was different and speeded up by the pre-crack (Figure 3). When the main cracks formed, beam can continue carrying body, load is mainly composed of shear zone and the main reinforcement concrete assumed jointly. Shear zone of the main diagonal crack extension and extension by the edge of the bottom of the beam is weak. Since the beams are pre-cracked, the concrete carries little tension at the crack and the GFRP is therefore required to resist the entire tension at that location. High strains occurred in the GFRP at the most stressed area, which is the location of the pre-crack.

![Figure 3: The crack development figure of GFRP reinforced concrete beams](image)

3.2 Shear test data

In the three-point shear test, Mean values of the load retention rate are given in Figure 4, where data from all kinds environments have been aggregated. The line slope inconsistent shows the different degradation degree, and the greater of the slope shows the more obvious degradation effect of GFRP reinforced concrete beam. In the alkaline environment, the load retention rate is the smallest, namely the loss of the ultimate load is the largest and the influence on shear performance is the most obvious, however, the environmental impact was intensified by crack on GFRP reinforced concrete beam. Since the same environment, the load retention rate of beams with pre-crack are about 11.4% to 11.7% smaller than those without pre-crack. The influence of crack not to ignore is proven by the shear test data.

Three vertical axis are specialized to analyze mean values of deflection at the load of 7.5kN in Figure 5. It is visible that the deflection values change trends of GFRP reinforced concrete beam are divided into two kinds, which respectively are the no consistent upward or downward trend of beams in outdoor environment or beams without pre-crack in tap water and the consistent upward or downward trend of beams in alkaline environment or beams with pre-crack in tap water environment. The obvious deterioration influence of alkaline environment on the shear performance of GFRP reinforced concrete beam has already been proved by the experiment, however, the environmental impact was intensified by crack on GFRP reinforced concrete beam, the maximum difference of the values can reached to 46.3%.
OS-Beams without pre-crack in outdoor environment;  
WS-Beams without pre-crack in tap water environment;  
AS-Beams without pre-crack in alkaline environment;  
OPS-Beams with pre-crack in tap water environment;  
WPS-Beams with pre-crack in tap water environment;  
APS-Beams with pre-crack in alkaline environment.

Figure 4. The ultimate load retention rate of beams

Figure 5. Mean values of deflection at the load of 7.5kN

3.3 P-CMOD curves Analysis

Figure 6. P-CMOD curves under different working conditions for 270 days

The whole curve reflects the relationship of the loading values (P) and the crack mouth opening displacement (CMOD) under different working conditions for 270 days (Figure 6). Comparative analyses of results reveal that the change trends of the P-CMOD curves are basically similar and in line with the trend of the bond-slip relationship curve. The outdoor without pre-crack conditions, the rate of CMOD value change is more slowly than beams with pre-crack at the early stage of loading, when load reaches a certain value, the CMOD value of GFRP reinforced concrete beam without pre-crack changes more slowly than before in tap water and alkaline environment, however, with pre-crack, consistent upward trend in the P-CMOD curve is observed.

4 CONCLUSIONS AND RECOMMENDATIONS

Concrete structures often work with cracks which provide a channel for harmful substances into the internal structure and make a certain influence on the internal GFRP bar. Therefore, the influence of the cracks cannot be ignored for the long-term durability researches of the GFRP reinforcement concrete structure. A unique set of experimental data on the fracture properties of GFRP reinforced concrete beams with pre-crack following sustained flexure and environmental exposure has been reported. While beams with pre-crack used in this investigation was largely influenced on the ultimate load retention rate, the deflection and P-CMOD curves, changes in shear performance with conditioning...
time and environment were detected, and the maximum difference of the ultimate load retention rate and the deflection can respectively reached to 38.5% and 46.3% in different environments.

However, the GFRP bar production technology and methods are different, and lead to the different response of GFRP bar to various environmental erosion, and this experiment only focused on the outdoor environment of Wuhan in China and 60°C alkaline environment, tap water environment. Therefore, more factors should be considered in order to comprehensive analyze the shear performance change rule of GFRP reinforced concrete structures.

ACKNOWLEDGMENTS

This research is supported by the National Natural Science Foundation of China (Grant No 51178361). Feng-hui Composite Material Co Ltd, Nanjing in China provided the GFRP bars. Many thanks are extended Mr. Sheng of Feng-hui Composite Material Co Ltd for his interest in and support of this investigation, and thank editors and anonymous reviewers for helpful comments and suggestions.

REFERENCES