

# Experimental Investigation on Flexural Behavior of Concrete Beams reinforced with GFRP Bar with Working Cracks

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**Abstract:** Based on 12 GFRP reinforced concrete beams with initial cracks, the bearing capacity, failure mode and crack propagation of strengthened concrete beams which considering the factors such as the initial crack and concrete grade was investigated through four-point bending test. The results showed that the initial crack have no obvious influence on the failure mode of GFRP reinforced concrete beam. Regardless of initial crack considerations, the strengthened concrete beams has damage with crush of compression zone concrete as load increasing. On the same concrete strength grade, the mid-span deflection of GFRP reinforced concrete beam with initial cracks is slightly larger than the values of GFRP concrete beam which regardless of the initial cracks. Concrete grade has an effect on stiffness of GFRP reinforced concrete beam with initial cracks. With the increase of concrete grade, the down-trend of bearing capacity caused by initial cracks has slowed down.

## 1. Introduction

Glass Fiber Reinforced Polymer bar have the advantages of high strength, light quality, corrosion resistance and electromagnetic resistance, it considered as a new kind of material which can replace steel reinforcement in corrosion environment and can not use steel bar in special environment. At present, the experimental research of GFRP reinforced concrete beams has been widely valued by the research institutes and engineering field of various countries <sup>[1]</sup>.

At present, the experimental study of GFRP reinforced concrete beams has been conducted and some results have been achieved. Gao et al<sup>[2]</sup> investigated the bending capacity of concrete beams reinforced with GFRP bars, the results showed that the crack width and deflection of FRP reinforced concrete beams are larger than that of reinforced concrete beams under the same conditions. Xue et al<sup>[3]</sup> conducted a systematic study on the bending capacity of the normal cross section of FRP reinforced concrete beams, the minimum reinforcement ratio of FRP reinforced concrete beams and the relationship between the reinforcement rate and the failure mode are determined. Zhang et al<sup>[4]</sup> also conducted the four point bending test, the deflection and bearing capacity of GFRP reinforced concrete beams and reinforced concrete beams are compared and analyzed under the same geometry and concrete strength.

An experimental study on bending performance of the reinforced concrete beams with prestressed GFRP bars was conducted in literature <sup>[5]</sup>, the load deflection curve of the prestressed GFRP reinforced concrete beams was obtained, and the whole loading process was analyzed. Zhang et al <sup>[6]</sup> established the numerical model of four-point bending the concrete beams reinforced with GFRP bars, the microscopic crack initiation and macroscopic damage processes of the two type beams were simulated, and the stress and fracture energy were analyzed to explore the internal damage mechanism of the two beams.

Alsayed<sup>[7]</sup> conducted a contrast test on the flexural performance of the GFRP reinforced concrete



beam with reinforced concrete beam, the results showed that the mechanics property of GFRP reinforced concrete beam was similar to reinforced concrete beam in many ways. But due to the low elastic modulus of GFRP bar, the deflection of GFRP reinforced concrete beam is bigger than the reinforced concrete beam under same circumstance. These conclusions were confirmed by Masmoudi<sup>[8]</sup> and Tegola<sup>[9]</sup>.

The above experimental research and theoretical analysis are conducted in hypothetical condition, but it ignores the fact that GFRP reinforced concrete beam not only bearing the sustained load, and often work with crack under service condition. At present, there is no research on the bending performance of GFRP reinforced concrete beams with working crack under service condition and sustained loading. Therefore, the bearing capacity, failure mode and crack propagation of strengthened concrete beams which considering the factors such as the initial crack and concrete grade was investigated. It also provides a reference for the application of GFRP reinforcement concrete structure in the civil engineering.

## 2. Experimental program

### 2.1 Test materials

The GFRP bars used in the study were provided by Fenghui composite materials Co., Ltd., Nanjing, China. This type of bars is made up of unidirectional roving of E-glass and epoxy vinyl ester resin. The bars appear as milky spiral sandblasting, and each screw is 14mm in length and 0.325mm in height. The mechanical properties of GFRP bar is shown in Table.1.

**Table 1** Mechanical properties of GFRP bar

Diameter (mm)	Density (kg/m <sup>3</sup> )	Ultimate tension (kN)	Tensile strength (MPa)	Elastic modulus (GPa)
10	2200	72	980	42

### 2.2 Specimens preparation

In this experiment, 24 GFRP reinforced concrete beams were produced. 12 of them were specimens with working cracks and 12 were controlled specimens. The specimen length is 1100mm and the section size is 80mm×110mm. considering the impact of concrete strength on the test, the specimens are cast in concrete with three different kinds of grades (C20, C30 and C40).

Preliminary four-point flexure tests were conducted to determine the ultimate bending moment of the beams and provided the original design data for the pre-cracked load. A group of GFRP bars embedded in concrete beams was prefabricated without cracks as a reference. The remaining beams were pre-cracked by four-point flexure tests after aging.

A homemade counterforce frame with steel frames and steel springs was used to apply flexural loads and produce stable cracks. The spring coefficient was 40 kN/mm (Fig. 1). The inner two load points were located 250 mm from the outer load points, and the two outer load points were located 50 mm inward from the ends of the beam. Failure in the four-point flexure tests occurred in a shear/compression mode at one of the inner load points at a mean applied moment of 0.9 kN·m. Beams were precracked at the bending moment of 0.37 kN·m.



**Figure 1** Loading equipment

In order to investigate the effect of working crack on the mechanical performance of GFRP

reinforced concrete beams, the specimens are divided into two groups. The group is shown in table 2. In the control group, the sustained load was applied directly.

**Table 2** Test groups

Specimen	Number	Length(mm)	Area (mm <sup>2</sup> )	Grade	Initial crack
B1-1	4	1100	80×110	C20	with
B1-2	4	1100	80×110	C20	without
B2-1	4	1100	80×110	C30	with
B2-2	4	1100	80×110	C30	without
B3-1	4	1100	80×110	C40	with
B3-2	4	1100	80×110	C40	without

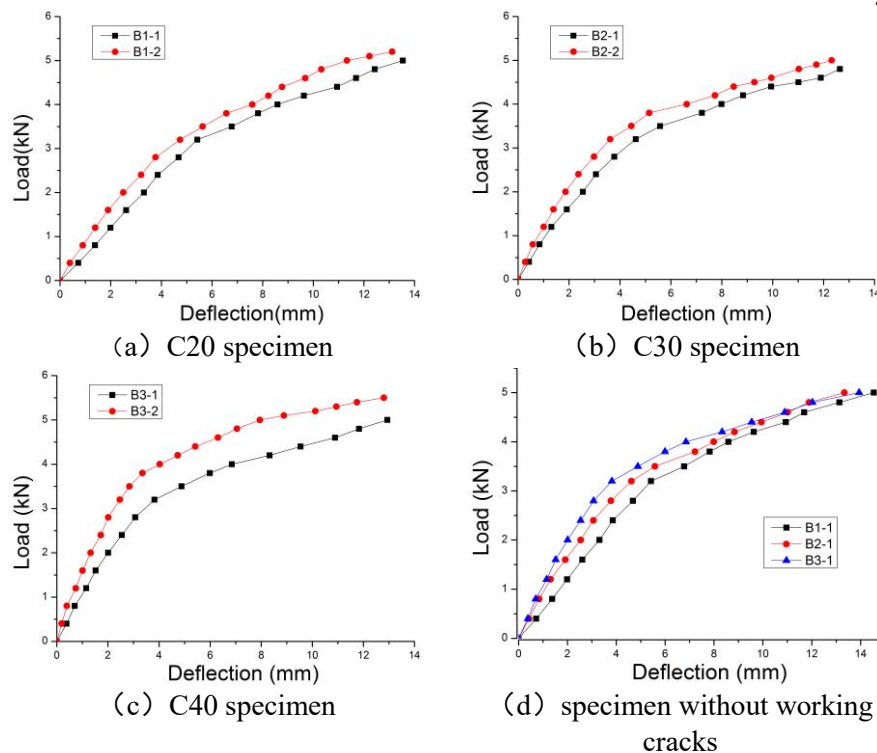
### 2.3 Loading scheme and test procedure

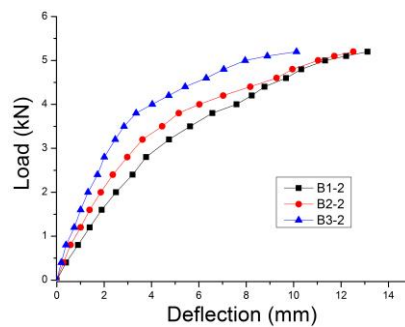
All the specimens were put in an indoor environment. An four-point flexure test was conducted to evaluate the bending capacity of GFRP bars embedded in beams environmentally conditioned with pre-cracking after 2 months. Five strain gauges, two dial gauges, and displacement gauges were fixed on the beams. Counter-force apparatus and hydraulic jack were specially designed to conduct the four-point flexure tests, and a data acquisition system was used to record the load value, the strain value and the mid-span displacement. 0.2kN was loaded at each level before cracking, while 0.1kN was loaded after crack. The load was loading to failure after the crack width become widen and deeper.

## 3. Test results and discussion

### 3.1 Load-deflection curve

The load-deflection curve of concrete beams reinforced with GFRP bars was shown in Fig.2.





(e) specimen with working cracks

**Figure 2** Load-deflection curve of different concrete grade

Fig. 2 is the load-deflection curve for different concrete grade specimens. It can be found out that the load-deflection curves of the specimens with and without the working cracks were indicates a double-linear property. Compared with the specimen without working crack, the mid-span deflection of the working crack specimen was slightly larger than that under the same concrete grade.

At the beginning of load, the specimen is in elastic state and the load-deflection curve is linear, deflection value of the specimen increases slowly with the load. The curve begins to turn a turning point when the load continues to increase to the cracking load. When the component is cracked, the tensile stress of the section is fully assumed by the GFRP bar and the section stiffness of the member is reduced, meanwhile, the growth rate of deflection is accelerated. The stiffness of the concrete beam can be degraded due to the existence of the crack, therefore, the fracture mode of the specimen with working crack is larger than that of the specimen without working crack under each load.

### 3.2 Crack propagation

All specimens showed different degrees of bending crack in pure bending section during the test. At the beginning of load, the crack at the bottom of the specimen with working cracks begin to stretch. As the load increases, the working crack continues to expand in the direction of the original cracking. When the load increases to the cracking load of the control group, the old crack was close to the top of the initial crack. The new crack begins to form when the load reaches about 20% of the ultimate bearing capacity, the old and new cracks were extended to form the first curved crack in the pure bending section.

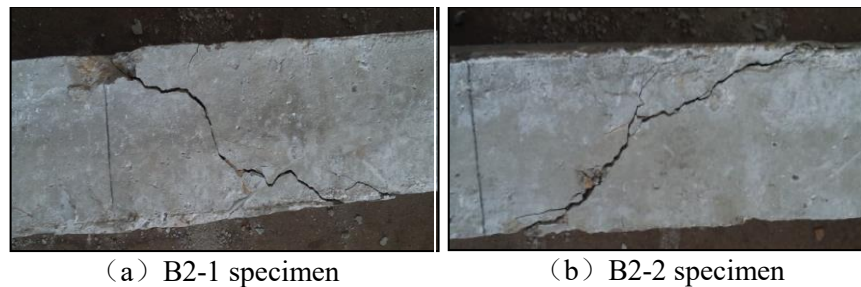
The width of the crack increases with the load and continues to expand along the depth direction of the beam. When the load is close to 70% of limit bearing capacity, new cracks appear at the bottom of the specimen and the average spacing of the cracks is smaller than before.



(a) B1-1 specimen

(b) B1-2 specimen

**Figure 3** Crack pattern of B1-1、B1-2

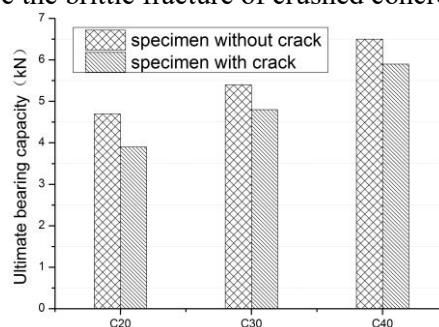


**Figure 4** Crack pattern of B2-1 and B2-2

As can be seen from Fig.3, the crack space of the specimen without working crack have little difference with the specimen that have working crack, and the crack extension path was similar. In addition, it can be found that the existence of working crack has no obvious effect on the failure of GFRP reinforced concrete beams through comparison with Fig.3 and Fig.4. The vertical cracks in specimen extends to the loading point ultimately with the load increased, and the horizontal crack appeared at the end of loading, which results the final failure of specimen due to the concrete crush at the loading point. The fundamental reason is that the stress concentration caused by the local pressure of the loading point.

### 3.3 Load bearing capacity

The ultimate bearing capacity of the specimens B1-1, B2-1 and B3-1 was 4.7kN, 5.4kN and 6.5kN respectively. As can be seen from Fig.5, the ultimate bearing capacity of the specimen increases slightly with the increase of concrete strength. Compared with C20 specimen, the ultimate bearing capacity of C30 and C40 specimens increased by 14.9% and 38.3% respectively. The results showed that C40 can be combined with the GFRP bars better compared with C20 and C30, and it can avoid the yield of the GFRP tendon before the brittle fracture of crushed concrete in compression zone.



**Figure 5** The ultimate bearing capacity of different specimens

The ultimate bearing capacity of B1-2, B2-2 and B3-2 was 3.9kN, 4.8kN and 5.9kN respectively. Compared with the specimen of B1-1, B2-1, B3-1, the ultimate bearing capacity decreased by 17.0%, 12.5% and 10.2% respectively. The ultimate bearing capacity of GFRP reinforced concrete beam is reduced in different degrees due to the existence of working crack. With the increased of concrete strength, the decrease trend is slowing down. It can be seen that the working crack has a negative effect on the ultimate bearing capacity of GFRP reinforced concrete beams, however, the influence will gradually decrease with the concrete strength.

## 4. Conclusion

(1) Compared with the specimen without working crack, the mid-span deflection of the working crack specimen was slightly larger than that under the same concrete grade. The concrete grade has an effect on the stiffness of GFRP reinforced concrete beam with working crack, with the increased of concrete strength, the decrease trend is slow down.



(2) The exist of working crack have no obvious influence on the specimen's failure mode, with the increase of load, the specimens with and without working crack were failure by concrete crushed in the compression zone. The stiffness of the concrete beam can be degraded due to the existence of the crack, therefore, the fracture mode of the specimen with working crack is larger than that of the specimen without working crack under each load.

(3) Compared with C20 and C30, C40 can be combined with the GFRP bar better, and it can avoid the yield of the GFRP tendon before the brittle fracture of crushed concrete in compression zone.

### References:

- [1] Bakis, C.E. Durability of GFRP Reinforcement Bars. CICE 2010 - The 5th International Conference on FRP Composites in Civil Engineering. September 27-29, 2010, Beijing, China
- [2] Gao Danying, Zhu Haitang, Li Chenchen. Research on the cross-sectional anti-cracking behavior of concrete beam with fiber reinforced polymer bars [J].Journal of Hydroelectric engineering, 2003, (4):54-59.
- [3] Xue Wei-chen, Zheng Qiao-wen, Yang Yu. Design recommendations on flexural capacity of FRP reinforced concrete beams [J].Engineering Mechanics, 2009, 26(1):79-85.
- [4] Zhang Zhi-qiang, Shi Xiao-quan, Li Zhi-ye. Experimental Investigation of Flexural Behavior of Concrete Beams Strengthened with GFRP [J]. Journal of Southwest Jiaotong University, 2011, 46(5):745-751
- [5] Zhang xue-zhong, Qian rui, Mao wei-bing. Study on the bending feature of prestressed concrete beams reinforced with GFRP [J]. Jiangsu Construction, 2003, 90(2):24-27.
- [6] Zhang Ya-fang, Yang Wen-long. Numerical analysis of four-point bending the concrete beams reinforced with glass fiber reinforced plastics and steel bars [J]. Journal of Shenzhen University (Science and Engineering), 2013, 30(4):379-384.
- [7] Alsayed S H. Flexural behavior of Concrete Beams Reinforced with GFRP Bars [J]. Cement and Concrete Composites.1998, 20.
- [8] Masmoudi R, Theriault M and Benmokrane B. Flexural Behavior of Concrete Beams Reinforced with Deformed Fiber Plastic Reinforcing Rods [J].ACI Structural Journal, 1998, 95(6):665-675.
- [9] Tegola A L. Actions for Verification of RC Structures with FRP Bars [J]. Journal of Composites for Construction. 1998, 2(3):145-148.
- [10] ACI 440.1R-06. Guide for the Design and Construction of Concrete Reinforced with FRP bars [S]. American Concrete Inst., Farmington Hills, 2006.
- [11] ACI 440.3R-04 Guide Test Methods for Fiber Reinforced Polymers (FRP) for Reinforcing or Strengthening Concrete Structures [S]. Farmington Hills: American Concrete Institution, 2004.