ISSN 2616-5767 Vol.4, Issue 5: 15-19, DOI: 10.25236/AJETS.2021.040503

Durability and Flexural properties of Concrete slabs with mixed GFRP bars and Steel bars

Yanru Ren[1, *]

[1]School of Civil Engineering and Architecture, University of Jinan, Jinan, China
**Corresponding author: 594278575@qq.com*

Abstract: *Many researchers have shown that it is engineering feasible to use fiber-reinforced polymer (FRP) bars instead of steel bars as the tension-affected main bars in reinforced concrete structures. However, concrete slabs strengthened with FRP bars are limited in the field of civil engineering. For example, the elastic modulus of FRP bars is low, and the ductility of the member is reduced due to the brittleness of FRP bars. To solve these problems as much as possible, scholars have adopted an idea that can use both FRP bars and steel bars in concrete members. There are still some problems with the bending behavior and durability of the proposed structural reinforcement, and further research is needed in this area. In this paper, the concrete slabs strengthened with GFRP reinforcement and reinforced mixing on the bending properties and durability of the experimental research, and some important findings are summarized.*

Keywords: *GFRP bars, steel bars, concrete slab, durability, flexural resistance*

1. Introduction

For a long time, the main causes for concrete structure damage caused by concrete durability deficiency are internal steel bar corrosion, freezing damage and physicochemical effects of rebar in corrosive environment [1]. Structural damage caused by steel bar corrosion has become the main influencing factor for concrete structure durability. FRP bars stand out from many new materials and are called the ideal replacement of steel bars. The main reason is that its corrosion resistance, high strength, light weight and electromagnetic insulation can fundamentally solve the steel corrosion caused by [2] the problem of insufficient durability of concrete structures.

Many researchers have tried many times to study the performance of FRP reinforced concrete structures [3-6]. However, according to many research results, the failure characteristic of FRP bars concrete slab is sudden brittle failure. In order to improve the normal performance of the plate, it is possible to combine the advantages of FRP bars and steel bars. The corrosion of steel bars in the structure can be prevented by the mixed use of FRP bars instead of steel bars in the corner area and steel bars in other positions. At present, many researchers have studied the performance of concrete structures reinforced with mixed FRP bars and steel bars for many times [7-9]. In contrast, the flexural and durability of reinforced concrete slabs are seldom studied together.

In this paper, the durability and bending properties of reinforced concrete slabs with steel bars and GFRP Bars are studied. Relevant research can understand the advantages of hybrid reinforced concrete slab and improve the application of FRP reinforced hybrid reinforced concrete structure in design and practical engineering.

2. Experimental details

2.1 The raw materials

2.1.1 Steel bars and GFRP bars

Plate tensile zone of stress reinforced with steel and glass fiber reinforced polymer (GFRP). The steel bar is hot-rolled ribbed steel bar with diameter of 10mm. The measured yield strength and elastic modulus are 388MPa and 204GPa respectively. Considering the same section area of the stress bars, GFRP bars with the same diameter are selected for GFRP bars. Ultimate strength and elastic modulus of 760 mpa and 40.8 GPa, respectively. In addition to the part of single-layer reinforcement is arranged in

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the force direction, the single-layer distribution reinforcement is also arranged, and the diameter of the steel bar 6 is placed every 200mm.

2.1.2 Concrete

The test board is made of ordinary Portland cement concrete. Concrete mixture ratio as shown in the table 1, the design strength of 30MPa. All the panels were poured horizontally and six 150mm diameter concrete cubes were prepared for each panel to determine the actual strength of the concrete. Three concrete cubes were directly subjected to compressive test after curing for 28 days, and the compressive test showed that the average of 28 d concrete compressive strength is 34.9Mpa. The remaining three concrete cubes were used for durability studies for wet and dry cycle tests.

Table 1: Concrete mix proportions.

Cement (kg/m3)	Stone (kg/m3)	Sand (kg/m3)	Water (kg/m3)	Specimen trength f_{cu} (MPa)
461	1250	512	175	34.9

2.2 Beam specimens design

There are three types of boards, with two boards cast for each type. More details about these bars are shown in Figure 1. A total of four specimen plates were prepared to study the effect of mixed rebar, each with a specimen size of 2300mm×1000mm×150mm. The samples included two rc slabs and four GFRP reinforced concrete slabs. In addition, in order to study the durability of mixed reinforced concrete slabs, we also carried out dry and wet cycle tests on three other slabs, and compared with the other three slabs.

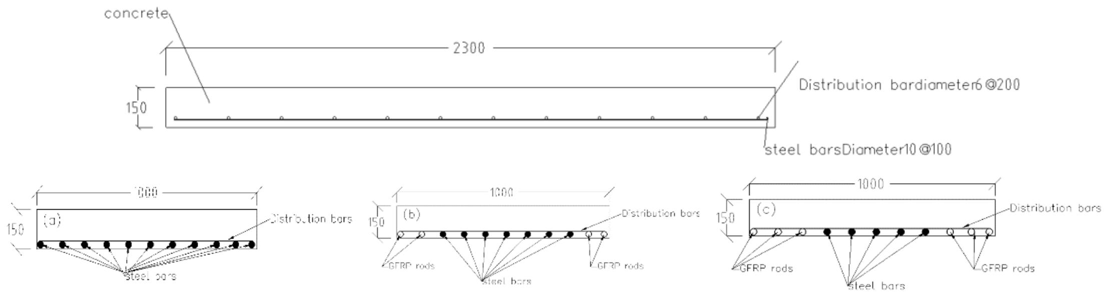

Figure 1: Specimen size and reinforcement diagram.

The three types of test plates are set as follows:

(1) All steel bars are arranged in one layer, with 11 bars in each layer, as shown in Figure 1 (a);

(2) Left and right sides of the configuration of a small amount of GFRP rebar, decorate a layer of about 2 reinforced with GFRP bar on each side, and seven steel bars are arranged in the middle, as shown in Figure 1 (b). The ratio of GFRP bars' sectional area to the steel bar's sectional area is 1.75; In the figure, solid circles represent steel bars and hollow elements represent GFRP bars (the same below).

(3) Left and right sides of the configuration is more GFRP rebar, decorate a layer of left and right sides of the 4 reinforced with GFRP bar, in the middle of three reinforced, as shown in Figure 1 (c). The ratio of GFRP bars' sectional area to the steel bar's sectional area is 2.67.

2.3 Experimental design and test method

Firstly,a preliminary treatment was carried out on the specimen: white lime paste was painted on the bottom and side surfaces of the plate, and a 50mm×50mm square was drawn on the specimen with an ink line, and strain gauges were pasted respectively, and displacement gauges were installed. In order to study the durability and flexural performance of mixed reinforced concrete slabs, two different methods will be used for verification in this experiment. The first method is on the plate bending test specimen directly after initial treatment, in order to study hybrid reinforced concrete plate (B1, B2, B3) bending performance. Another method is the plate specimen under dry-wet cycling test after preliminary treatment, and then to bend test, mixed reinforced concrete slab (A1, A2, A3) the durability of the research. Dry-wet cycling test in sodium chloride solution concentration was 5%, the dry-wet circulation ratio of 1:1, each cycle six days, a total of 30 cycle.

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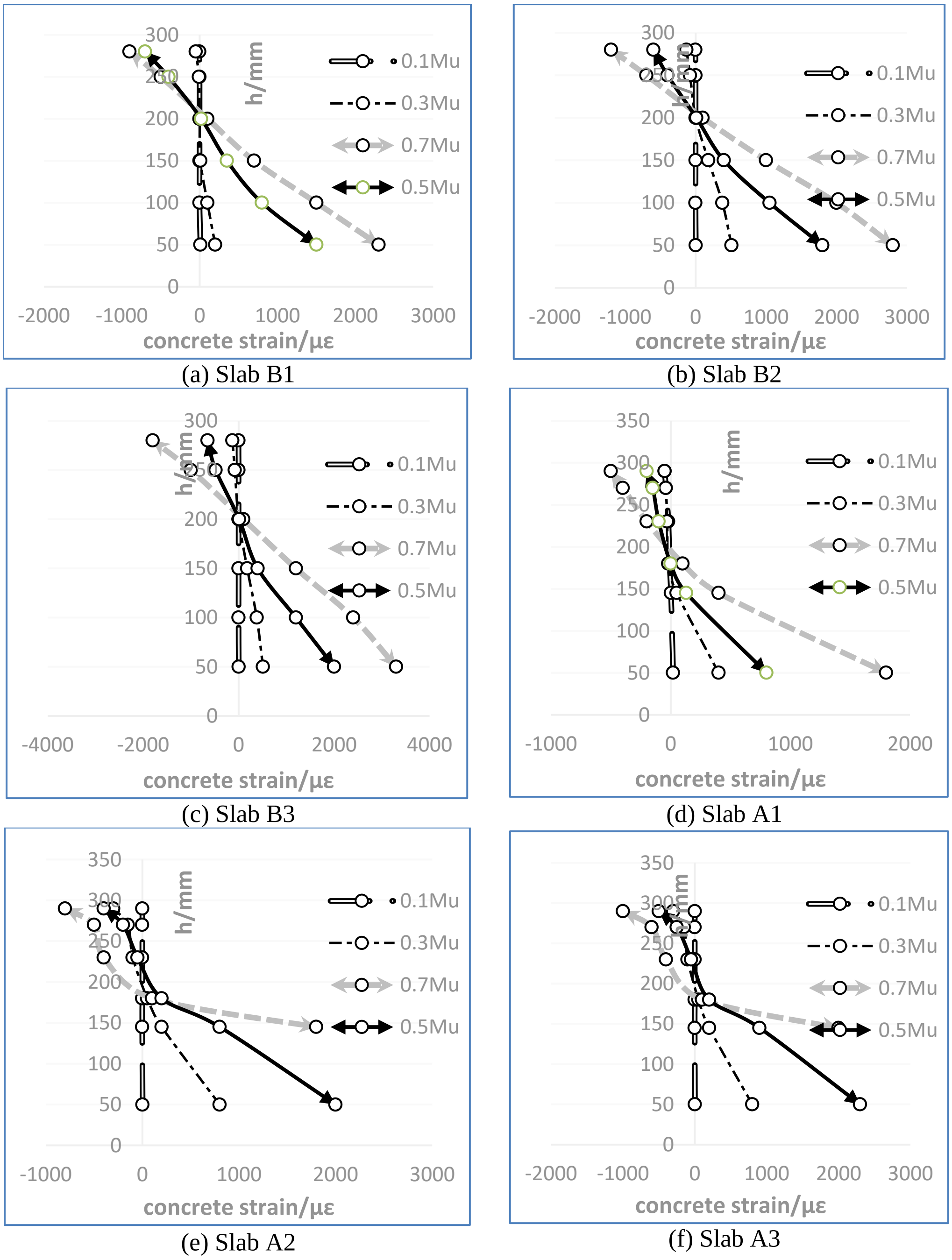
2.4 Experimental pressurization method

The 50T self-balancing system was used for bending test of all specimens. Two cushion blocks are arranged at 1/3 span of the board face, the length of which is 1000mm. By distributing beams and rollers to apply a concentrated load on the pad, the plate is uniformly stressed within the pad. Each specimen needs to be preloaded before formal loading to adjust the strain gauge and sensor accuracy. Pre-loading is divided into three stages, each stage takes 15% of the ultimate load, and then unloading by stages; Formal loading, again using graded loading, where each level is pressurized for a period of time until it breaks. The displacement meter and strain gauge installed during this process automatically detect the skewness and strain of the concrete slab.



(a) Slab B1 (b) Slab B2
(c) Slab B3 (d) Slab A1
(e) Slab A2 (f) Slab A3

Figure 2: Strain distribution of plate.

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3. Experimental results and analysis

3.1 Strain condition

The measured strain values of the six plates along the mid-span plate depth under different load levels are shown in FIG. 2. It can be seen that the strain distribution plate (B2 and B3) of mixed reinforced concrete has a small strain on the section before cracking, which is similar to that of reinforced concrete plate (B1), and the variation law of deformation conforms to the assumption of plane section. Concrete is basically in the elastic working stage, stress and stress into direct proportion, compression zone and tensile zone concrete stress distribution diagram for the triangle. The concrete strain produced by reinforced concrete slab can increase to 2200με; When GFRP bars are introduced in the corner area, the strain limit increases to 3300με, indicating that the GFRP bars introduced in the corner area of concrete slab can significantly improve the strain of concrete.

Concrete slabs with the same reinforcement form (slabs B1, A1; Plate B2, A2; The strain of slabs B3 and A3 is also different in different environments. The strain of slabs treated by dry-wet cycle test is less than that of slabs not treated, and the difference of strain between the two specimens is about 700με.

3.2 Ultimate flexural capacity

The relation between deflection and bending moment of concrete slab is shown in FIG. 3. The bending moment-deflection curves of all specimens at the initial stage are linear. The cracking load is mainly decided by the tensile strength of concrete. The cracking load of mixed concrete slab is very close to that of reinforced concrete slab. When the bending moment increases to the cracking moment M, the first crack is usually in the middle area of the slab. After cracking, the deflection begins to increase, and the slope of deflection moment - deflection curve changes. Because the elastic modulus of GFRP bars is much smaller than that of steel bars, the deflection of GFRP bars mixed concrete slab increases faster than that of reinforced concrete slab after concrete cracking. However, when the steel bars enter the yield, the deflection of the reinforced concrete slab increases sharply while the bearing moment increases little. At this time, the growth rate of the deflection is reversed to that of the mixed concrete slab.

In the case of the same overall section reinforcement ratio, the flexural capacity of the mixed concrete slab will be different because of the different cross-sectional areas of GFRP bars. The greater the ratio of GFRP bars to steel bars, the more prominent the flexural capacity of the mixed concrete slab.

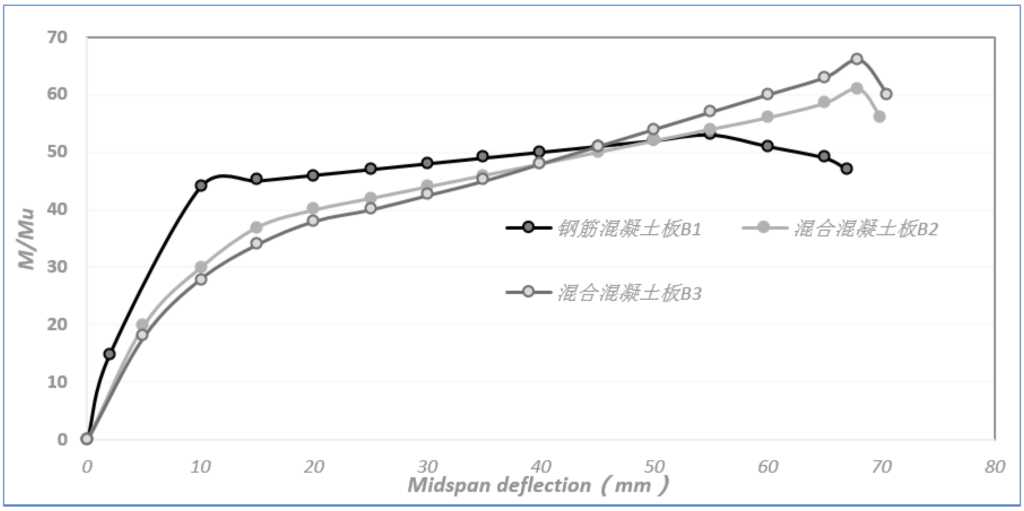

Figure 3: Comparison of deflection and bending moment of concrete slab.

Table 2 shows the failure mode and bearing capacity of the specimens. The reinforced concrete slab is crushed in the post-yielding compression zone after two different treatment methods. However, the failure modes of mixed reinforced concrete slabs are different. The failure phenomenon of B2, A2 and A3 under different maximum bearing capacity is that GFRP bars break, but the GFRB bars of SLAB B3 do not break.

ISSN 2616-5767 Vol.4, Issue 5: 15-19, DOI: 10.25236/AJETS.2021.040503

According to the above experimental results, it is feasible to replace the corner steel bar in the concrete slab with GFRP bars, and the durability of concrete structure can be improved by arranging the proportion of GFRP bars and steel bars reasonably.

Table 2: Experimental results of plate bearing capacity.

Specimen	M_u (MPa)	Failure mode
B1	51.2	Reinforcement yield and concrete crushing in compression zone
B2	60.3	Steel yield, GFRP bar fracture and the concrete in the compression zone is crushed
B3	66.5	The steel bars yield, GFRP bars are not broken and the concrete in the compression zone is crushed
A1	43.4	Reinforcement yield and concrete crushing in compression zone
A2	48.2	Steel yield, GFRP bar fracture and the concrete in the compression zone is crushed
A3	53.3	Steel yield, GFRP bar fracture and the concrete in the compression zone is crushed

4. Conclusion

By analyzing the experimental results of durability and bending properties of concrete slabs reinforced with GRFP bars and steel bars, the following conclusions are drawn.

1) The deformation variation law of the concrete slab strengthened with mixed GFRP and steel bars is consistent with the assumption of plane section, and the cracking load of concrete is similar. Introducing GFRP bars into the corner of concrete slab can significantly improve the strain of concrete, and the strain of GRFP reinforced mixed concrete slab is greater than that of reinforced concrete slab.

2) Under the same load level, the reinforcing bar before yielding GRFP the midspan deflection of reinforced concrete plate is greater than the midspan deflection of reinforced concrete plate, after dry wet cycling test treatment of plate bending deflection curve of the basic similar

3) In the reinforced concrete plate structure, using GFRP rebar to replace the Angle area ordinary reinforced concrete slab is feasible, and will not reduce the flexural bearing capacity of concrete, in the whole plate screen reinforcement ratio at the same time, the bending capacity with the increase of the GFRP reinforcement and reinforced area ratio increase, through the reasonable arrangement of GFRP reinforcement and reinforcement ratio can improve the durability of the concrete structure.

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