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Finite Element Analysis and Influence Factors of Flexural Behavior of HFRP Reinforced Concrete Beams

Finite Element Analysis and Influence Factors of Flexural Behavior of HFRP Reinforced Concrete Beams

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Abstract: HFRP (Hybrid Fiber Reinforced Plastics) ribs are a new type of composite rib made of a mixture of two or more continuous reinforcing fibers. Since the HFRP ribs have a "pseudo-yield" phase similar to that of steel bars, the mechanical properties of HFRP reinforced concrete structures are quite different from those of single FRP reinforced concrete, and should be studied in depth. In this paper, the finite element analysis of the hybrid effect of HFRP bars and the flexural behaviour of HFRP reinforced concrete beams is carried out. The ANSYS finite element analysis software is used to simulate the bending test of carbon/glass HFRP reinforced concrete beams with three different hybrid ratios. The calculation results are compared with the experimental results, and the rationality of the finite element model is verified. On this basis, the influence of mixing ratio, reinforcement ratio and concrete strength on the deflection of concrete beams is further analysed.

1. Instruction:

At present, the most widely used structural type in civil engineering is reinforced concrete structure. Among them, steel and concrete are the most widely used building materials in the structure, but there are some problems in the use process: for example, self-importance. Steel bars are easy to rust and so on. At present, the durability of reinforced concrete has become an urgent problem to be solved. According to the engineering practice and application of the developed countries for many years, the cost for solving this problem is also high.

In recent years, fiber reinforced polymer composites (FRP) have been widely used as an alternative material for steel in civil engineering. They have higher specific strength, specific stiffness, corrosion resistance and stronger than steel. The design and other advantages have been tried in new structures in recent years, and have achieved good social and economic benefits [1]. However, due to the shortcomings of the deformation ability of single FRP ribs, the wide application of FRP reinforced concrete structures is restricted. The most effective way to solve this problem is to make hybrid fiber (HFRP, Hybrid Fiber Reinforced Plastics) ribs by hybrid technology to give full play to the advantages of different fibers, to develop strengths and avoid weaknesses, and finally to achieve the comprehensive mechanical properties of FRP ribs [2].

2. Introduction to HFRP

2.1 Composition and Forming Technology of HFRP Bar

HFRP rib is a fiber reinforced rib that is made by pultrusion of two or more types of continuous reinforcing fiber plastics according to different mixing ratios by matching and lengthening, thereby producing a synergistic hybrid effect.

The HFRP rib is formed by injecting and drawing two or more kinds of reinforcing fibers into a resin material. The production process of resin-based composite materials mainly includes hand lay-up molding process, spray molding process, winding forming process, pultrusion process and press molding process [3].

2.2 Hybrid Effect and Hybrid Mode of HFRP Bar

At present, the hybrid methods of fiber hybrid structures mainly include intra-layer hybrid, inter-layer hybrid, uniform hybrid, sandwich structure and combined hybrid structure [4]. For the inter-layer hybrid method, it is characterized by flexibility and simplicity, but the fiber type and the mixing ratio selected have a great influence on the mechanical properties of the hybrid fiber, so the hybrid method for different fibers can be mixed. HFRP with excellent mechanical properties is one of the research directions of composite materials in recent years.

The so-called "hybrid effect " [5] refers to the phenomenon that some properties of hybrid fiber deviate from the calculation result of the mixed law, and can be divided into two cases: negative hybrid effect and forward hybrid effect. The phenomenon of calculating the value higher than the mixing law; and the "negative hybrid effect" refers to the phenomenon lower than the calculated value of the mixed law.

The confounding effect is not an algebraic sum of the properties of several single fiber composites, but a phenomenon unique to hybrid fibers, in which the advantages of a single FRP are not only preserved, but also manifest differently due to the difference in reinforcing fibers used in the mixing. Excellent comprehensive performance characteristics, easy to use in engineering applications under different factors.

3. Finite element simulation

3.1 Survey of HFRP reinforced concrete beam specimens

Three kinds of hybrid carbon/glass hybrid fiber reinforced ribs were used in concrete beams to simulate the bending performance of concrete beams. Among them, the carbon/glass hybrid fiber ribs are made of domestically produced E-glass fiber and carbon fiber produced by Toray of Japan as the reinforcing material, and the performance parameters of the two fibers are shown in Table 1 and Table 2, respectively.

Table 1.Basic properties of Toray T700 12K carbon fiber

Tensile Strength/MPa	Tensile Modulus /GPa	Elongation at Break/%	Density /KN·m-3
5020	230	2.2	18

Table 2.Basic properties of E-glass fiber

Tensile Strength /MPa	Density /KN·m-3	Elongation at Break %	Tensile Modulus /GPa
3500	25.4	3.0	72

Since the hybrid fiber ribs used in concrete have to work in the high alkaline environment of concrete for a long time, the resin matrix in this test simulates epoxy vinyl ester resin with excellent alkali resistance and mechanical properties. The basic performance is shown in Table 3.

Table 3. Basic properties of epoxy vinyl ester resin

Solid Content /%	Viscosity /MPa	Tensile Strength /MPa	Tensile Modulus /GPa	Elongation at Break /%
55	450	87.5	3.22	6.7

In this experiment, helical HFRP bars are used to improve the bonding force between hybrid fiber reinforced materials and concrete, which makes the fiber bundles not easy to slip off. The mechanical

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properties of three kinds of carbon/glass hybrid fiber reinforced materials with different hybrid ratios are shown in Table 4.

Table 4.Basic properties of HFRP bar

Hybrid Ratio (Vol%)	Diameter (mm)	Cross-sectional Area (mm^2)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Elongation at Break (%)
C15/G35-HFRP Bars	9.5	70.8	771.85	65.26	1.15
C20/G30-HFRP Bars	9.5	70.8	868.69	76.07	1.18
C25/G25-HFRP Bars	9.5	70.8	1033.89	87.55	1.17

3.2 Finite element calculation results of BL1-2 test beam

Based on the results of numerical simulation, the mid-span moment-deflection curve of HFRP beams is drawn. The relationship between the curve and the normal use of the beams is directly related. The bending moment-deflection data of the specimens are recorded through the finite element software. The bending moment-deflection curve is shown in Figure 4. It can be seen from the figure that the experimental results are in good agreement with the numerical simulation results of ANSYS.

The first stage starts from the initial loading to the middle pure curved section. The load at this stage is approximately 20% of the ultimate load compared to reinforced concrete. During this period, the concrete is in an elastic phase, and its stress-strain relationship is basically proportional. Then, with the increase of the load, the tensile strain of the concrete at the edge of the tension zone is close to the limit value, and the concrete stress pattern of the tension zone shows a curve change. However, in this stage, the concrete beam is joined for the full section and the concrete has not been cracked. In the second stage, when the bending moment reaches the cracking moment, the first crack begins to appear in the pure curved section of the concrete beam, and the concrete beam enters the seam working stage. At this time, in the cracking position, the load in the tension zone is entirely borne by the hybrid fiber ribs, and the concrete in the tension zone has been withdrawn from work. In addition, compared with the other two single FRP rib beams, the three kinds of hybrid fiber girders exhibit a certain ductility, and their ductility is consistent with the low elastic modulus glass in the hybrid fiber ribs. The volume of the fiber tendon increases and the deflection increases accordingly.

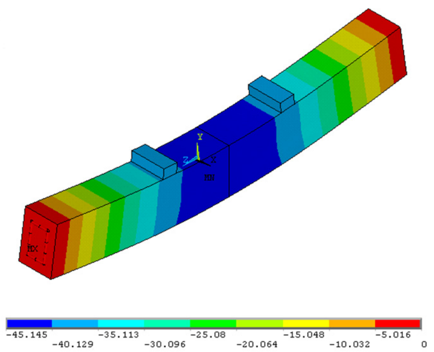

Figure 1. The limit deformation about Y direction of BL1-2 test beam

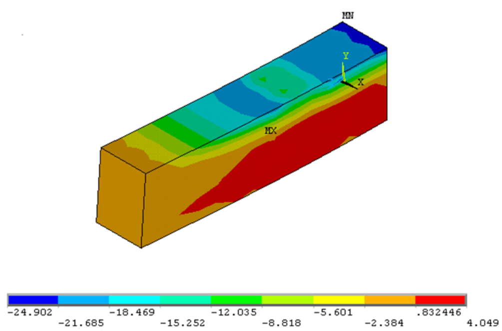

Figure 2. The limit axial stress of BL1-2beam

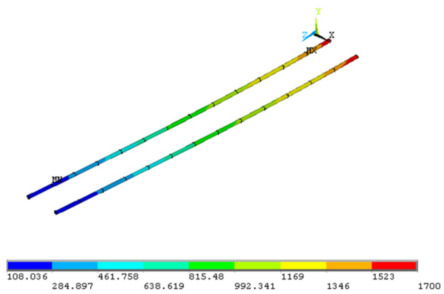

Figure 3. The limit state axial stress of HFRP bar

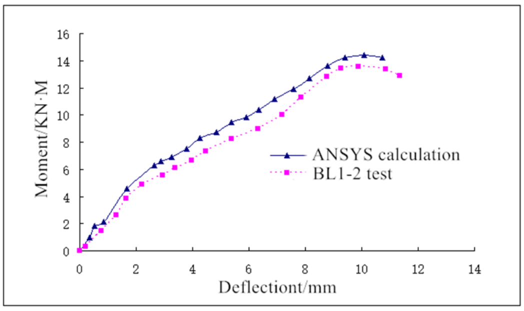

Figure 4. Test and calculated results about moment-deflection relationship of BL1-2 test beam

4. Influencing factors of deflection of concrete beams reinforced with HFRP bars

(1) Effect of C/G Hybrid Ratio

The deflection performance of concrete beams is directly affected by the mixing ratio of CFRP/GFRP. The deflection of concrete beams decreases with the increase of the proportion of carbon fibers in hybrid fiber reinforced bars. Moreover, the larger the proportion of CFRP, the steeper the descending section, the smaller the stability value after descending, and the closer the failure performance of concrete beams is to brittleness; the smaller the proportion of CFRP, the smoother the descending section is, and the larger the stability value after descending, the closer the failure of concrete beams is to ductility.

(2) Effect of reinforcement ratio of HFRP bars

In the range of boundary reinforcement, the deflection of the hybrid fiber reinforced concrete beam decreases with the increase of the reinforcement ratio. And under the same bending moment (10KNM), when the reinforcement ratio is increased by 49.8%, the deflection is reduced by 12.6%.

(3) Effect of concrete strength

The deflection of HFRP reinforced concrete beams is not affected by the strength of concrete, which is similar to reinforced concrete flexural members. The main reason is that the concrete strength has a limited effect on the stiffness of the specimen. Under the lower bending moment, the deflection of the specimen is very close; but as the bending moment increases, the deflection decreases slightly with the increase of concrete strength.

5.Conclusions

(1) Under the same conditions, the deflection of the beam in the HFRP tendon decreases with the increase of the volume fraction of carbon fiber; the bending stiffness of the beam calculated by finite element analysis is larger than the measured value.

(2) The ANSYS finite element method is used to simulate the bending test of the hybrid fiber reinforced concrete beam. The calculated results are basically consistent with the measured values. However, the bending stiffness of the beam calculated by finite element analysis is larger than the measured value. Therefore, an effective stiffness prediction model for hybrid fiber reinforced concrete members is proposed, and the calculated deflection values agree well with the measured values.

(3) The main factors affecting the deflection of HFRP reinforced concrete beams are: carbon/glass mixing ratio, reinforcement ratio and concrete strength. However, from the analysis of the finite element results, it can be seen that the deflection is relatively affected by the carbon glass mixing ratio and the reinforcement ratio, and is less affected by the concrete strength.

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