Experimental research on flexural performance of concrete beams strengthened by hybrid fiber CGFRP sheet

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Abstract. Concrete beams strengthened with Hybrid Fiber carbon/glass fiber strengthened polymer (C/GFRP) sheet can not only improve beam ductility, but reduce the cost of the project effectively. It is plays an important engineering application of meaning. In this paper, three concrete beams are strengthened with different fiber (CFRP, C / GFRP and GFRP) in the normal section and a loading failure test. The stress characteristics, failure form, reasonable reinforcement mode, strain condition, bearing capacity, rigidity and deformation capacity of C / GFRP hybrid fiber strengthened beams were studied. The results showed that the flexural load capability and the ductility of the beams strengthened with hybrid C/GFRP are better than that of normal FRP.

1. Introduction
In recent years, the method of strengthening concrete members with high strength carbon fiber is gradually adopted by civil engineer, while the high cost of carbon fiber makes it less widely useful. Previous experiment [1-3] indicate that bearing capacity of using carbon fiber strengthened structure improves effectively, but the cost of material is high, element is poor ductility; The performance of beams with glass fiber is opposite to that of CFRP. This method, which can reduce the cost [4] and improve the comprehensive utilization of the material to improve the Material utilization ratio.

The performance of carbon fiber and glass fiber mixed together is better than that of single material. The high elongation fiber (GFRP) afford the extra load of the low elongation of fiber (CFRP) fracture. Hybrid fiber delay from micro to macro damage process. The average fracture strain of hybrid fiber is improved effectively. The tensile strength of the low elongation fibers in the mixed state is higher (even significantly higher) than the tensile strength of a single fiber. After the low-elongation fibers break, they can work together with the high-elongation fibers in the form of short fibers until all of the fibers are broken. [3] The mechanical properties of hybrid fiber materials in the structure are better than those of the single material stack.

2. Experiment program

2.1 Specimen details and reinforcement scheme
Four specimen beams were tested, with a length of 2000mm and the same rectangular cross section of 120x200mm. The concrete strength is C20 (cube compressive strength measured is 23.6MPa). HRP335 is adopted to serve as longitudinal steel bar. HRP300 is adopted to serve as stirrup and top steel bar, yield strength is measured to be 362MPa and 298 MPa respectively. B beam is strengthened. Two layers of carbon fiber is pasted on CB beam, a layer of carbon fiber and two-layer glass fiber is pasted on CGB beam, the 3 layer of glass fiber is pasted on GB beams. Full-length fibers that were 100mm in...
width were placed in the bottom of four concrete beams and the two ends of fibers should be anchored by U-shape fiber. Reinforcement ways is showed in figure 2. Adhesive tensile strength for seven day is 30 Mpa. The performance index of fiber in table 1.

![Figure1](image.jpg)

**Figure1**: element size, reinforcing bars and fiber strengthened

### 2.2 Experimental facility, experimental scheme and loading system

**Table 1.** Experiment parameters of fiber properties.

| Fiber type     | Tensile strength/MPa | Elastic modulus/GPa | Ultimate tensile rate/% | thickness |
|----------------|-----------------------|---------------------|-------------------------|-----------|
| Carbon fiber   | 3450(2100)            | 234.5               | 1.5                     | 0.13      |
| Glass fiber    | (320)                 | (18)                | (3.2)                   | (0.4)     |

Notes, the values in parentheses in the table are measured valued of cured fabric.

Beam of 2 groups under vertical loads at three-dividing point, using a hydraulic jack load, the beams are placed below the hydraulic jack load, two load sensors are arranged between the loading point and the distribution of beam load, imposed by the measurement, the test beam cross is equipped with a dial indicator at the bottom of it, 5 strain gauges should be equipped on the side of the middle part of the beam layout, to measure the strain variation along the beam of strong concrete.

The whole loading process is controlled by load, before the element cracked, load is 5 KN per level, after the element cracking, load is 10 KN per level. When the experimental ended, concrete crushed or fiber fracture, stripping and load do not increase.

### 3. Main test results and analysis

#### 3.1 The main experimental results

The measured ultimate load, ultimate displacement and failure mode of all elements are showed in table 2, the direction of strain of mid span of CGB beam is vertical, the strain is showed in figure 2, the bearing capacity of element is showed in figure 3, the load-displacement curve is showed in figure 4.

**Table 2.** Main characteristic index of the experimental result of beam.

| Beam number | B         | CB        | CGB       | GB         |
|-------------|-----------|-----------|-----------|------------|
| Ultimate load | 16.4(18.84) | 34.3      | 25.7      | 20.6       |
| Ultimate displacement | 6.2 | 11.9 | 14.6 | 16.8 |
| Stress and failure mode | Rare damage | failure mode | failure mode | failure modes I |

Notes, the ultimate load of the beam in the table is the experimental value (calculated value).

#### 3.2 Analysis of result

##### 3.2.1 Loading feature and failure mode.

Because B beam have a little steel bars, cracks appear in the lower part of the beam B, crack up quickly, concrete of press section is crushed suddenly, it is brittle nature, it belongs to less steel damage, ultimate load value is less than the theoretical value (calculation of proper steel bars). cracks appear in the lower part of the beam CB, cracks up slowly, after cracks through the axis, the cracks on both sides develop toward the loading point, cracks in the middle develop vertically, concrete of compressive zone crushed, beam lose bearing capacity, CFRP
sheets in the bottom of beam were close to fracture, at the same time U-shaped anchor fibers became deboned from the surface of beam.

![Figure 2.CGB strain.](image1)

![Figure 3. Loading capacity of element.](image2)

![Figure 4. Loading-displacement curve.](image3)

CGB cracks are a dense, vertical extension, deformation is obvious, the fibers fabric is broken suddenly inside the anchor fiber of one end and fibers break into strips to became deboned from the bottom of beam with concrete, concrete was crushed and destroyed. The distribution of GB cracks is relatively uniform, the development process of CGB beam and GB beam is similar, the failure process of GB beam belongs to ductile failure.

According to the loading process, the phenomenon of bonding failure does not appear in the whole experiment, even if many layers of fiber are bonded. The anchor fiber avoids the occurrence of bonding failure. From the three reinforcement member failure modes and similar documents, there are two failure modes, failure mode I, the longitudinal reinforcement of element tensile area is yielded, after fiber break, concrete is crushed and damaged; failure modes of II, the concrete has been crushed and fiber cannot be broken.

3.2.2 Section strain. The strain of each load is measured in the experiment, the strain of the beam height of CGB under the load of two (P=15KN and P=20KN)is showed in figure three. Section strain is basically in line with the plane section assumption. Good bond capacity was found between fiber and concrete. But cracks appear at the bottom of the beam, with the increase in load, the fiber strain of the bottom of beam increase is more obvious.

3.2.3 Ultimate loading capacity. Because of the brittle failure of the contrast beam B, the loading capacity is measured to low, so bearing capacity of proper-strengthened element is compared with the bearing capacity of unstrengthened element. The loading capacity of the reinforcement elements is improved extenty, beam CB was the largest, followed by CGB and GB, 82%, 36% and 9%, respectively. From the similar experimental research, [1-3] the loading capacity ratio of beams strengthened with different fibers is not big, and the little of element and the concrete strength distribution of contingency are related, and two fiber tensile strength is different in the experiment. It
can be proved that hybrid fiber reinforcement can effectively improve the loading capacity of flexural elements.

3.2.4 Rigidity and deformation capacity. The load-displacement curve of the beam is showed in figure 4, the rigidity of the four members did not differ much at the initial stage of loading, indicating that the fiber played no significant role. When the load increases to 10 kN or more, the elements are cracked basically, beam CB showed greater rigidity, while the CGB, GB second. As the load increases, the rigidity and deformation capacity of the three strengthened elements are just opposite to each other, the rigidity of beam GB is the smallest, but the deformation capacity is the largest, and the rigidity and deformation capacity of CGB are larger. It can be concluded that the late rigidity of element strengthened with CGFRP hybrid fiber is smaller than that of element strengthened with CFRP, but larger than GFRP strengthened element, its deformation ability is bigger than CFRP and GFRP. Generally speaking, CGB has better ductility under the condition of high loading capacity.

4. Conclusion
(1) Under the premise of ensuring the bond strength and anchoring measures, the failure mode of the fiber reinforcement member can be divided into two types.
(2) The U-shaped anchoring bar can effectively avoid the failure of anchoring.
(3) The cross-sectional strain of fiber-strengthened beams with C / GFRP interlayer is in line with the plane section assumption, between the fiber layers and between the fiber and concrete can be bonded well, they can achieve the same effect of force.
(4) The bearing capacity of low reinforcement flexural element C / GFRP hybrid fiber can be improve significantly.
(5) The later-stage deformation capacity of C / GFRP strengthened element is larger than CFRP, smaller than GFRP, and the beam has better ductility under the condition of high loading capacity. Through the research in this paper, it is proved that the C/GFRP layer between the form of hybrid fiber strengthened concrete beams to improve the anti-flexural ability is feasible.

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