Experimental Study on Carbon Fiber Concrete Beams

Xiaochu Wang1,2, Xiaomei Nie1,* and Long Xiong1

1 Shenyang University, Liaoning, Shenyang, 110044, China
2 The Key Laboratory of Geoenvironmental Engineering, Liaoning, Shenyang, 110044, China

*Corresponding author email: niexiaomei1989@126.com

Abstract. The influence of the length of carbon fiber on the deflection and strain of carbon fiber concrete beams was studied by testing the flexural capacity of the normal section of four carbon fiber concrete beams. The results show that the length of carbon fiber has a certain influence on the strength of reinforced concrete beams. The failure deflection of fiber concrete beams increases with the increase of the length of carbon fiber. Carbon fiber can improve the brittle failure of concrete beams. No matter how long the carbon fiber is, the cracking load and ultimate load of CFRC beam are not different from that of ordinary concrete beam.

Keywords: Carbon fiber concrete beam; Strain distribution; Failure deflection.

1. Introduction
Carbon fiber is a kind of material with high elastic modulus and high strength. Adding short-cut carbon fiber into concrete can effectively improve the impact resistance, tensile strength and flexural strength of concrete. This method can not only reduce the dry shrinkage of concrete, but also improve its wear resistance and improve the damping capacity of concrete [1]. Carbon Fiber Reinforced Concrete (CFRC) is a new composite material made by adding Carbon Fiber to ordinary Concrete [2]. Ming Xin et al. [3] reviewed the research progress on the influence of fiber on the durability of concrete in recent years from four aspects: freeze-thaw resistance, sulfate erosion resistance, carbonization resistance and impermeability, analyzed and summarized the influence of fiber on freeze-thaw resistance, sulfate erosion resistance, carbonization resistance and impermeability. Fiber can inhibit the formation of concrete cracks, improve tensile and bending strength and impermeability, enhance anti-aging ability and durability, and improve the service life of concrete [4]. When the content of carbon fiber in concrete reaches 1.4%, the anti-impact performance is the best, and if the content of carbon fiber continues to increase, the anti-impact performance decreases [5]. Carbon fiber is beneficial to the improvement of compressive strength of concrete. With the increase of carbon fiber content, the concrete resistance first decreases sharply, then slows down and tends to stabilize, and the optimal carbon fiber content is around 0.7% [6]. Yongzhi Xu et al. [7] prepared carbon fiber concrete specimens and conducted water pressure test on the specimens. Their research showed that carbon fiber and silicon powder had obvious effects on the impervious property of concrete, while the length of carbon fiber had no significant effect on the impervious property of concrete. Xiangqin Du et al. [8] studied the performance of CFRP through experiments, and the results showed that the compressive strength and splitting strength both increased first and then decreased with the increase of fiber content. Concrete is the most widely used building material in the engineering field, but its inherent defects such as high brittleness, poor tensile strength,
poor toughness and other problems hinder its development. Adding fiber to concrete can effectively improve these defects [9]. Cracks in concrete not only affect the integrity of components, but also affect their service life. At present, there are many researches on the anti-freeze, anti-permeability and anti-impact of common concrete and carbon fiber test blocks at home and abroad, but few researches on the influence of carbon fiber length on the performance of CFRC beams. In this study, four CFRC beams were tested to mainly study their working principle, mid-span deflection and load-strain curve, so as to provide reference for the later study on mechanical properties of CFRC.

2. Specimen Preparation

In this experiment, a total of 4 carbon fiber reinforced concrete beams are designed, and their dimensions are 200mm×300mm×2900mm. The strength of concrete is C30. The maximum particle size of coarse bone is no more than 18cm. Fine bone particles are well graded medium sand. The longitudinal tensile steel bar is HRB335 grade hot rolled steel bar with a diameter of 16mm. The diameter of round steel bars of stirrups and frame stiffeners are 8 mm with spacing of 100mm. The fiber is 3k carbon fiber with lengths of 10mm, 30mm and 50 mm respectively.

2.1. Arrangement of Measuring Points

To obtain the vertical forces, one tension-compression load cells is used. The dynamic signal testing and analysis system was used for data processing. When measuring the strain of steel and concrete, paste the strain gauge at 1/4, 1/3, 1/2, 2/3 and 3/4 of the beam. A displacement meter and dial gauge are placed at the midspan to measure the deformation.

2.2. Loading Scheme

The loading system is as follows: preload twice, preload value takes 70% cracking load, apply it in three times, and unload it in two times after loading. Ensure that all test equipment can be used normally, and start loading formally after 10min; Graded monotone loading is used for formal loading, with 5kN for each grade and the load value shall not exceed 10% of the ultimate load. When it is loaded to 90% of the expected cracking load, the load value becomes 2kN per grade, and 5kN per grade after the first crack appears. When it reaches 80% of the ultimate load, the load value becomes 4kN per grade and is loaded to the failure of the specimen.

2.3. Test Results and Analysis

The cracking load and ultimate load of CFRC beams and plain concrete beams of different carbon fiber lengths were obtained through experiments, and the specific values are shown in table 1. As shown in the table, no matter how long the carbon fiber is, the cracking load and ultimate load of CFRC beam are not different from that of ordinary concrete beam.

| Specimen | Fiber length (mm) | Cracking load(kN) | Ultimate load(kN) |
|----------|------------------|-------------------|------------------|
| C-1      | 0                | 12.1              | 71               |
| C-2      | 10               | 11.2              | 72.2             |
| C-3      | 30               | 13.3              | 74.3             |
| C-4      | 50               | 14.1              | 71.1             |

3. Cross Section Strain Distribution

The strain distribution along the beam section height of concrete beams under different loads can be obtained from the test, as shown in Figure 1. It can be seen from the figure that, at the initial stage of loading, the strain of each specimen at different positions in the mid-span showed a linear change trend. With the increase of load, the strain deviated from the distribution of the flat section, and the changes between specimen C-2 and C-4 were obvious with maximum bottom strain. The strain at the bottom of the specimen is the largest, and the strain at the middle and upper part is zero. Regardless of the length of
the carbon fiber, the axis with the normal stress equal to zero in the direction of the positive section of each carbon fiber concrete beam is about 25 mm in the specimen, and the sum axis is closer to the tensile side than the neutral axis of the specimen C-1.

3.1. Load and Deflection Analysis
The relationship curve between load and deflection of CFRC beam is obtained through the test, as shown in Figure 2. As shown in the figure, the deflection change of the ordinary concrete beam is slower than that of the CFRC beam at the initial stage of loading. When the deflection reaches about 5mm, the deflection change of the ordinary concrete beam is obvious, and the deflection change of the CFRC beam is moderate without obvious inflection point. When the maximum load is reached, the deflection value of the CFRC beam is smaller than that of the plain concrete beam. This is mainly due to the anti-cracking effect of carbon fiber, which enhances the tensile strength of the concrete beam and makes the deformation of the beam more uniform. Therefore, carbon fiber can effectively improve the brittle failure of the concrete beam, thus increasing the cracking load of the concrete beam. No matter how the carbon fiber length changes, the load-deflection curves of specimens C-2, C-3 and C-4 remain basically the same. When the maximum load is reached, the failure deflection of CFRC beams increases with the increase of the carbon fiber length.

3.2. Load and Strain Analysis
In order to study the working mechanism of the stressed steel bar and concrete, the concrete and the stressed steel bar strain in the same plane, as shown in Figure 3. It can be seen from the figure that: at the initial stage of loading, the basic change trend of load-strain is the same, and the longitudinal stress in all specimens is the joint work of steel bar and concrete. The surface strain of concrete and reinforcement increases with the increase of load. The strain curve of concrete is parallel to that of steel bar, which indicates that there is no slip between steel bar and concrete. When the load of 47.3 kN, there will be no strain of concrete, concrete beams and CFRC beam strain continues to increase. This is mainly due to the low tensile strength of concrete, the rapid development of concrete surface cracks when loading to cracking load strain gauge tensile fracture, the rapid development of common concrete beam surface cracks, brittle failure of concrete beam, and the development of CFRC beam cracks slower than that of common concrete beam, carbon fiber delayed the cracking of test beam. With the increase of the length of carbon fiber, the strain of concrete and reinforcement decreases first and then increases when the specimen is damaged, which shows that the length of carbon fiber has a certain influence on the strength of reinforced concrete beams.
Figure 1. Strain distribution in section.

Figure 2. The Load-deformation curves. Figure 3. The curve of load-strain.

4. Conclusion
(1) Carbon fiber can effectively improve the deformation capacity of concrete, and the failure deflection of fiber concrete beams increases with the increase of carbon fiber length;
(2) During the stress process of the specimen, the steel bar and the concrete work in harmony and bear the force together. No matter how long the carbon fiber is, the cracking load and ultimate load of CFRC beam are not different from that of ordinary concrete beam.
(3) Carbon fiber can improve the brittle failure of concrete beams and improve the cracking load of concrete beams. The length of carbon fiber has a certain influence on the strength of reinforced concrete beams.

Acknowledgement
This work was supported by the Liao Ning Revitalization Talents Program (Project Name: Research on the Key Technology of Application of High - performance of the New -type antonym Material; The project number: XLYC1802018). There is no conflict of interest.
References

[1] Min Hou, Yan Tao, Zhong Tao, Dong Chai, Xiaohong Chen. Basic mechanical properties and analysis of chopped carbon fiber reinforced concrete [J]. Concrete, 2020(01): 74-77.

[2] Dongyue Cao. Force Sensitive Properties of Carbon Fiber Reinforced Concrete and Its Preliminary Application in Monitoring of Shaft Lining [D]. China university of mining and technology, 2018.

[3] Ming Xin, Xuezhi Wang, Huan Tong. Summary of Research on Durability of Fiber Concrete [J]. Journal of Liaoning University of Technology (Natural Science Edition), 2020, 40(01): 35-39.

[4] Song Qin. Discussion on Technology and Application of Fiber Reinforced Concrete [J]. Value engineering, 2019, 38(28): 271-273.

[5] Qingfeng Chen, Shaoshuai Li, Longze Yu, Yuhan Wang. Study on the impact resistance of carbon fiber concrete [J]. Journal of Henan Institute of Engineering, 2019, 31(04): 28-31.

[6] Tianwen Hu, Guichen Zhang. Conductive and heat property research for carbon fiber concrete [J]. Sichuan Building Science, 2018, 44(06): 96-100.

[7] Yongzhi Xu, Lifang Chen. Experimental Study on Impermeability of Carbon Fiber-reinforced Concrete [J]. Journal of Xuchang University, 2018, 37(04): 31-35.

[8] Xiangqin Du, Zhilong Liu. Research on the influence of carbon fiber on the mechanical properties of concrete [J]. Concrete, 2018(04): 91-94.

[9] Xiaowei Li. Experimental Research of Basic Mechanical Properties and Early Mechanical Properties of Different Kinds of Fiber Reinforced Concrete [D]. Anhui University of Science and Technology, 2017.