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Experimental Study on Mechanical Properties of Carbon Fiber Reinforced Concrete

Tianhang Wang*

School of Civil Engineering, Liaoning Petrochemical University, Fushun Liaoning 113001, China

*Corresponding Author

Abstract

To investigate the effects of different water-cement ratios and carbon fiber content on the compressive and splitting tensile strength of concrete, this experiment was designed with four water-cement ratios and four carbon fiber contents. The four water-cement ratios were 0.35, 0.38, 0.41, and 0.44, while the four carbon fiber contents were 0%, 0.3%, 0.6%, and 0.9%. The experimental results showed that: 1. The compressive strength and splitting tensile strength of concrete initially increased and then decreased with the increase in water-cement ratio and carbon fiber content, reaching their maximum when the water-cement ratio was 0.38; 2. When the carbon fiber content exceeded 0.3%, the uneven distribution of carbon fibers within the concrete weakened the interfacial bonding properties, thereby reducing the strength of the concrete.

Keywords

Carbon Fiber, Water-cement Ratio, Concrete, Mmechanical Properties.

1. Introduction

The influencing factors of concrete are multifaceted. The water-cement ratio is one of the key parameters. A too high water-cement ratio will increase the distance between cement particles and weaken the bond between the cement paste and aggregates. On the other hand, a too low water-cement ratio will lead to insufficient hydration of cement, affecting the strength development and making the concrete less workable, which is not conducive to molding[1,2].

Due to the significant improvement of various properties of concrete by adding fiber materials, fiber-reinforced concrete has gradually attracted attention. Carbon fiber, with its excellent elastic modulus and compressive strength, has become one of the commonly used fiber materials in construction engineering. Adding it to cement-based composites can improve the performance of the materials. [3-5]. Carbon fiber has excellent tensile properties, while concrete has outstanding compressive performance. The combination of the two complements each other: carbon fiber improves the tensile properties of concrete, and concrete provides compressive support for carbon fiber, ultimately forming a high-performance composite material system[6]. Liu Hongtao [7] found that with the increase of carbon fiber content, the compressive strength and splitting tensile strength of concrete first increase and then decrease. Zhou Le et al. [8] pointed out that carbon fiber can improve the brittle failure characteristics of concrete. Yin Junhong et al. [9] further confirmed this rule in C30 and C40 concrete, and the increase in tensile strength was more significant than that in compressive strength.

Therefore, in this paper, 72 concrete specimens were prepared by designing 4 water-cement ratios (0.35, 0.38, 0.41, 0.44) and 4 carbon fiber contents (0%, 0.3%, 0.6%, 0.9%) to explore the influence of different water-cement ratios and carbon fiber contents on the compressive and splitting tensile strengths of concrete.

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2. Experimental Overview

2.1. Experimental Materials

Experimental materials: 42.5 grade ordinary Portland cement produced by Yangchun Cement Company in the city; medium sand from Fushun; crushed river pebbles from Fushun; tap water from Laboratory 108 of Liaoning Shihua University; water reducer is polycarboxylate water reducer; 9mm T700-12K carbon fiber produced by Carbonex Technology (Shenzhen) Co., Ltd. The performance of carbon fiber is detailed in Table 1, and the carbon fiber is shown in Figure 1.

Figure 1. T700-12K Carbon Fiber

Table 1. Performance Indicators of Carbon Fiber

Tensile Strength/MPa	4900
Diameter/μm	7
Elastic Modulus/GPa	230
Bulk Density/(g·cm³)	0.4
Length/mm	9

2.2. Concrete Mix Proportion

This experiment utilized four different water-cement ratios: 0.35, 0.38, 0.41, and 0.44, along with four carbon fiber incorporation rates: 0%, 0.3%, 0.6%, and 0.9%. The mix proportions were designed in accordance with the relevant requirements of the standard "Specification for Mix Proportion Design of Ordinary Concrete" (JGJ55-2011) [9]. The designed mix proportions for the experimental concrete are detailed in Table 2. Here, PC denotes plain concrete, BF denotes carbon fiber reinforced concrete, 0.35, 0.38, 0.41, and 0.44 represent the different water-cement ratios, and 0%, 0.3%, 0.6%, and 0.9% represent the different carbon fiber incorporation rates. The water-reducing admixture was added at 0.5% of the cementitious material.

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Table 2. Concrete Mix Ratio (Kg/m3)

Specimen number	Cement	Water	Stones	Sand	Water reducer	Carbon fiber
PC-0.35-0.0	542	190	1168	500	2.71	0.00
BF-0.35-0.3	542	190	1168	500	2.71	7.20
BF-0.35-0.6	542	190	1168	500	2.71	14.40
BF-0.35-0.9	542	190	1168	500	2.71	21.60
PC-0.38-0.0	500	190	1197	513	2.50	0.00
BF-0.38-0.3	500	190	1197	513	2.50	7.20
BF-0.38-0.6	500	190	1197	513	2.50	14.40

Continued from Table 2

Specimen number	Cement	Water	Stones	Sand	Water reducer	Carbon fiber
BF-0.38-0.9	500	190	1197	513	2.50	21.60
PC-0.41-0.0	463	190	1223	524	2.32	0.00
BF-0.41-0.3	463	190	1223	524	2.32	7.20
BF-0.41-0.6	463	190	1223	524	2.32	14.40
BF-0.41-0.9	463	190	1223	524	2.32	21.60
PC-0.44-0.0	431	190	1245	534	2.20	0.00
BF-0.44-0.3	431	190	1245	534	2.20	7.20
BF-0.44-0.6	431	190	1245	534	2.20	14.40
BF-0.44-0.9	431	190	1245	534	2.20	21.60

2.3. Preparation of Concrete

In this experiment, the dry mixing method was employed to prepare carbon fiber reinforced concrete. Initially, the coarse and fine aggregates were thoroughly mixed with cement. Subsequently, carbon fibers were evenly dispersed into the mixture and stirred. Finally, the water-reducing admixture and water were added, and the mixture was stirred until a uniform concrete slurry was achieved. The slurry was then poured into molds to form concrete cube specimens. After preparation, the specimens were placed in a curing chamber (maintained at 20-22°C and 95-97% humidity) in Laboratory 110 of the Civil Engineering Experimental Building at Liaoning Petrochemical University for two days before demolding. They were then cured for 28 days before being removed for mechanical property testing. The selection of test parameters and the testing procedure adhered to the national standard GB/T 50081-2002 "Standard for Test Method of Mechanical Properties on Ordinary Concrete" [10].

2.4. Testing Methods

In accordance with GB/T 50081-2019 "Standard for Test Methods of Physical and Mechanical Properties of Concrete" [11], a YAW-2000 uniaxial compression testing machine (loading rate of 2.4 kN/s) was used to determine the 28-day compressive strength and splitting tensile strength. The testing setup and specimens are illustrated in Figure 2.

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Figure 2. Testing Equipment

3. Results and Analysis

3.1. Failure Modes

Figure 3. Failure process of ordinary concrete

Figure 4. Failure process of carbon fiber concrete

By comparing Figures 3 and 4, it is observed that plain concrete emits a low and dull cracking sound during the loading and failure process, indicating the development of fractures. In contrast, carbon fiber-reinforced concrete produces not only the sound of crack propagation but also the sound of carbon fibers being pulled apart during the loading and failure process. This suggests that carbon fibers contribute their tensile properties during the compressive failure of concrete. Based on the failure phenomena shown in the figures, it can be concluded that the addition of carbon fibers to concrete at room temperature effectively mitigates the brittle failure of concrete, reduces spalling, and improves crack development.

3.2. Compressive Strength

3.2.1. Effect of Water-Cement Ratio on Compressive Strength of Concrete

references at a time may be put in one set of brackets [3, 4]. The references are to be numbered in the order in which they are cited in the text and are to be listed at the end of the contribution under a heading References, see Figure 1.

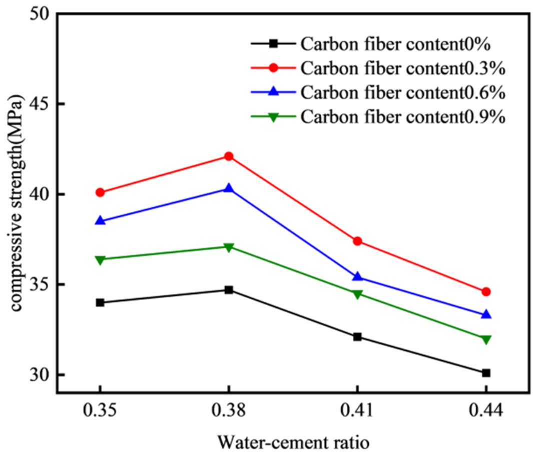

Figure 5. Compressive strength of concrete at room temperature

As shown in Figure 5, under different carbon fiber incorporation rates (0%-0.9%), concrete specimens with a water-cement ratio of 0.38 exhibited the optimal compressive strength. Specifically, when the carbon fiber incorporation rate was 0%, the compressive strength of specimens with a water-cement ratio of 0.38 increased by 1.86%, 8.11%, and 15.17% compared to specimens with water-cement ratios of 0.35, 0.41, and 0.44, respectively. When the incorporation rate was 0.3%, the improvement ranged from 4.99% to 21.79%; at 0.6%, it ranged from 4.50% to 21.04%; and at 0.9%, it ranged from 2.02% to 15.82%. This pattern indicates that a water-cement ratio of 0.38 significantly optimizes the compressive performance of concrete, and the incorporation of carbon fibers further enhances this effect, with the most notable improvement observed at a 0.3% incorporation rate.

3.2.2. Effect of Carbon Fiber Incorporation Rate on Compressive Strength of Concrete

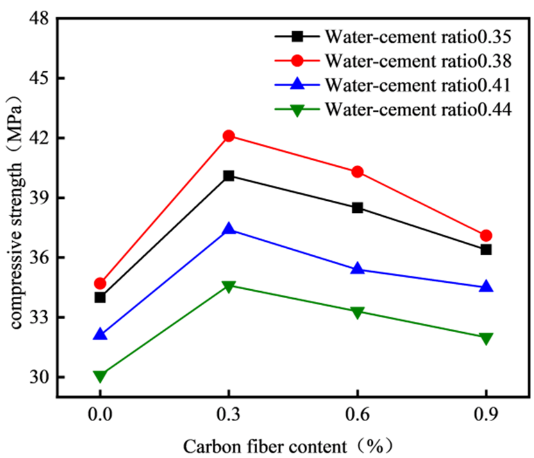

Figure 6. Compressive strength of concrete at room temperature

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Figure 6 shows that when the water-cement ratio was 0.35, the compressive strength of specimens with a 0.3% incorporation rate increased by 17.83%, 13.22%, and 6.86% compared to specimens with incorporation rates of 0%, 0.6%, and 0.9%, respectively. At a water-cement ratio of 0.38, the increases were 21.44%, 16.15%, and 7.02%; at 0.41, they were 16.53%, 10.29%, and 7.59%; and at 0.44, they were 14.84%, 10.52%, and 6.42%.

3.3. Splitting Tensile Strength

3.3.1. Effect of Water-Cement Ratio on Splitting Tensile Strength of Concrete

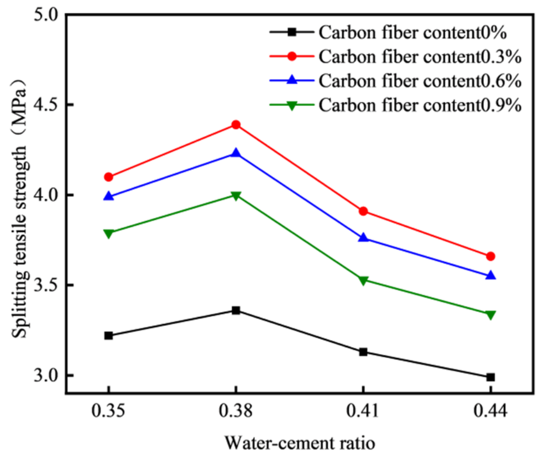

Figure 7. Tensile strength of concrete splitting at room temperature

The results in Figure 7 indicate that, under different carbon fiber incorporation rates (0%-0.9%), concrete specimens with a water-cement ratio of 0.38 exhibited the optimal splitting tensile strength. Specifically, when the carbon fiber incorporation rate was 0%, the splitting tensile strength of specimens with a water-cement ratio of 0.38 increased by 4.14%, 7.13%, and 12.39% compared to specimens with water-cement ratios of 0.35, 0.41, and 0.44, respectively. When the incorporation rate was 0.3%, the improvement ranged from 7.16% to 19.84%; at 0.6%, it ranged from 5.93% to 19.04%; and at 0.9%, it ranged from 5.54% to 19.98%.

3.3.2. Effect of Carbon Fiber Incorporation Rate on Splitting Tensile Strength of Concrete

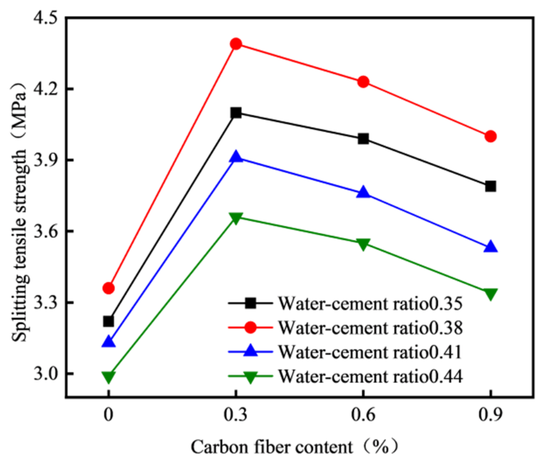

Figure 8. Tensile strength of concrete splitting at room temperature

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As shown in Figure 8, under different water-cement ratios (0.35-0.44), concrete specimens with a carbon fiber incorporation rate of 0.3% exhibited the optimal splitting tensile strength. Specifically, when the water-cement ratio was 0.35, the splitting tensile strength of specimens with a 0.3% incorporation rate increased by 27.09%, 23.89%, and 17.68% compared to specimens with incorporation rates of 0%, 0.6%, and 0.9%, respectively. At a water-cement ratio of 0.38, the increases were 30.78%, 26.02%, and 19.27%; at 0.41, they were 24.89%, 20.11%, and 12.67%; and at 0.44, they were 22.66%, 18.97%, and 11.72%.

The reason for this is that carbon fibers can make the internal stress distribution in concrete more continuous and uniform during the hardening stage, thereby reducing the generation of microcracks to some extent. Additionally, when concrete is subjected to external loads, carbon fibers act as bridges to transfer loads within the concrete, fully utilizing their tensile properties, which enhances the compressive and splitting tensile strength of the concrete. However, excessive incorporation of carbon fibers can lead to issues such as fiber agglomeration and uneven distribution. When the incorporation rate exceeds a critical value, both the compressive and splitting tensile strength of the concrete begin to decline.

4. Conclusion

1. The strength of concrete initially increases and then decreases with the increase in carbon fiber incorporation rate and water-cement ratio. When the water-cement ratio is 0.38 and the carbon fiber incorporation rate is 0.3%, the compressive and splitting tensile strength of the concrete reach their optimal values, increasing by 22.04% and 30.78%, respectively, compared to other mix proportions.

2. An appropriate amount of carbon fiber can improve the internal stress distribution of concrete, enhancing its compressive and tensile properties. However, excessive incorporation (beyond 0.3%) can weaken the interfacial bonding performance.

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