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Current Status of Research on Direct Tensile Testing Methods for Fiber Concrete

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Minireview Article

ABSTRACT

Due to the weak tensile strength of traditional concrete, relatively few concrete direct tensile tests (DTT) have been carried out for a long time, and many specifications and standards do not provide detailed guidance on its operation process. It was not until the birth of steel fiber concrete materials such as SFRC that the research on the tensile properties of SFRC was developed. There are three commonly used test methods to measure the tensile strength of concrete, namely: splitting tube test; (2) beam deflection test; (3) direct tension test. The first two tests do not give true tensile strength because the tensile stress is indirectly applied to the specimen. Only direct tensile testing can obtain the true tensile strength under uniform uniaxial tension. So far, domestic and foreign academic circles have not unified the form of steel fiber concrete and concrete axial tension test specimens and the axial tension test method, making the test results quite scattered. First, this article summarizes the direct tension methods currently used in fiber concrete, secondly compares the advantages and disadvantages of various direct tension test methods, and finally looks forward to the phased results and shortcomings of current research.

Keywords: Fiber reinforced concrete; uniaxial tensile strength.

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1. INTRODUCTION

Concrete is currently the most widely used and consumed building material in the world. However, the significant shortcomings of concrete materials are low tensile strength, poor crack resistance, and poor toughness. Adding steel fibers to concrete can improve the brittle behavior of concrete, thereby increasing its ability to absorb energy [1-4]. Steel fiber reinforced concrete (SFRC) plays an important role in the construction of high-rise buildings, long-span bridges and offshore structures due to its higher strength and energy absorption capabilities and better tensile strength.

The uniaxial strength of concrete refers to the compressive capacity of concrete under unidirectional force. Since there are certain differences in the performance and mix ratio of concrete itself, the uniaxial strength of concrete will also be different. Generally speaking, the unit of uniaxial strength of concrete is megapascal (MPa). The uniaxial strength of concrete is one of the important indicators to measure the performance of concrete. It plays a vital role in the seismic resistance and load-bearing capacity of concrete structures. Therefore, the test of concrete uniaxial strength is an important part of concrete engineering design and construction.

2. OVERVIEW OF EXISTING CONCRETE TENSILE METHODS

There are three commonly used test methods to measure the tensile strength of concrete, namely: (1) bending and tensile test [5]; (2) splitting tube test [6]; (3) direct tensile test. “The first two tests do not give true tensile strength because the tensile stress is indirectly applied to the specimen. In the split cylinder test, a concrete cylinder is placed horizontally between the pressure plates of a compressor, and a compressive load is applied on two diametrically opposite edges of the cylinder until the cylinder fails by splitting. In a beam bending test, a concrete beam is subjected to bending by applying a center point or third point load until the beam fails due to bending. So neither method produces true tensile strength. This is because in both methods, the assessment of tensile strength is based on the assumption that concrete is linearly elastic before failure, whereas in reality, as concrete approaches failure, the stress-strain curve becomes nonlinear. Only direct tensile testing can obtain the true tensile strength under uniform uniaxial tension. In addition, it obtains the full range of tensile stress-strain curves for all stages including pre-crack, post-crack and strain-softening failure stages, which is used to observe any strain hardening and determine the energy absorption during failure” [7]. For direct tensile testing methods, the following are summarized:

In early 1928 Gonnerman and Shuman [8] conducted “direct tensile tests on concrete cylinders using bolted steel strap clamps with leather friction surfaces to clamp and pull the ends of the specimens”. In the mid-1980s, Saito and Shah et al. [9,10] used “friction clamps to clamp both ends of the specimen and steel nails at the ends of the specimen to apply tensile loads and conducted direct tensile tests on concrete prism specimens, such as Shown in Figs. 1(A) and (B)”. However, an inevitable problem with these methods is the generation of secondary stress at the end of the specimen. This end effect will lead to uneven stress distribution in the specimen, causing local damage to the end, and the measured Tensile strength will be significantly reduced. To avoid this end effect. Xie and Zhang et al. [11,12] enlarged the ends of prismatic concrete specimens to form dumbbell-shaped concrete specimens for testing. However, due to changes in cross-sectional dimensions along the length, the tensile stress produced by the specimens was not Evenly distributed, even on the same cross-section, as shown in Fig. 1(C). Through the above overview, direct tensile test specimens can be divided into three types, namely dumbbell-shaped, cylindrical and prismatic specimens.

Benard et al. [13] studied “the performance of plain concrete and steel fiber concrete under direct tensile fatigue loading, and tested dumbbell-shaped specimens with different amounts of steel fiber volume content (0, 0.75 and 1.5%). From the test results, the deformation curves of plain concrete and steel fiber concrete are similar, thus the relationship between the fatigue life and secondary strain rate of plain concrete and steel fiber concrete under compression can be obtained. In addition, under the same loading parameters, the fatigue life of steel fiber concrete increases as the steel fiber content increases from 0 to 1.5%”.

Yan et al. [14] used “a servo hydraulic testing machine to study the effect of strain rate on the tensile strength, elastic modulus, critical strain, Poisson's ratio and energy absorption capacity of dumbbell concrete. The results show that the strength becomes greater with increasing strain rate. The presence of free water in concrete has an important influence on the strain rate dependence; the strength of saturated concrete increases significantly with increasing strain rate. Compared to concrete at room temperature, strength growth is less sensitive to strain rate at low temperatures of 30°C. The strain rate increase in elastic modulus is not as significant as that in tensile strength. Temperature conditions have little effect on the strain rate sensitivity and critical strain of the elastic modulus. The critical strain increases slightly with increasing strain rate. The strain rate effect of moisture content has an opposite trend on the critical strain than on the elastic modulus. Higher strength concrete has a greater critical strain than lower strength concrete. No clear increase in Poisson's ratio was observed. For saturated concrete and concrete with normal moisture content, the energy absorption capacity increases significantly with increasing strain rate".

Shi et al. [15] studied the mechanical properties of two types of SFRC with different fiber volume contents (straight fiber and hook fiber) under uniaxial compression and tension. The results show that the elastic modulus of the specimen in tension is not equal to the elastic modulus in compression. For plain concrete, the compressive elastic modulus is 2.2 times the tensile elastic modulus, and for steel fiber concrete, the ratio is close to 1.5. Although the addition of fiber does not significantly change the compressive strength of concrete, it improves the cracking behavior of concrete under compression. The improvement in the tensile properties of concrete is even more significant. SFRC with straight steel fibers has higher tensile strength than SFRC with curved steel fibers, which may be due to the greater number of fiber-cement matrix interfaces. However, hook-type steel fiber concrete showed better performance in terms of ductility, residual strength and toughness. A modified fiber reinforcement index is proposed for different fiber shapes. Based on calibration using SFRC toughness, the fiber shape factor of straight fibers is close to 0.70 for both compression and tension, which means that the reinforcing effect of straight fibers used in this study is approximately 70% that of hooked fibers.

Zheng et al. [16] proposed "a new direct tensile test method for prismatic specimens, which uses bonded steel end plates to apply tensile loads to concrete. The device is shown in Fig. 2. Three-dimensional finite element analysis of the test assembly showed that the tensile stress transferred to the specimen was distributed very uniformly. Approximately 200 prism blocks were tested with this new method. The frequency distribution of fracture locations shows that fracture locations are randomly distributed along the length of the specimen. The correlation between the measured tensile strength and the fracture location revealed that the fracture location has little effect on the measured tensile strength. Therefore, it can be concluded that there are no end effects in the specimens that would lead to a significant reduction in the tensile strength results".

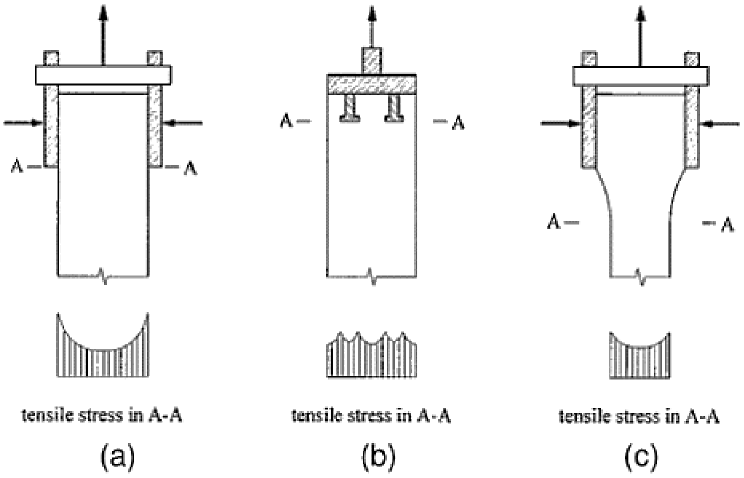

Fig.1. Secondary stress caused by direct tension at the end of the specimen: (a) friction clamping of the end; (b) stud embedded in concrete at the end; (c) friction handle and enlarged end

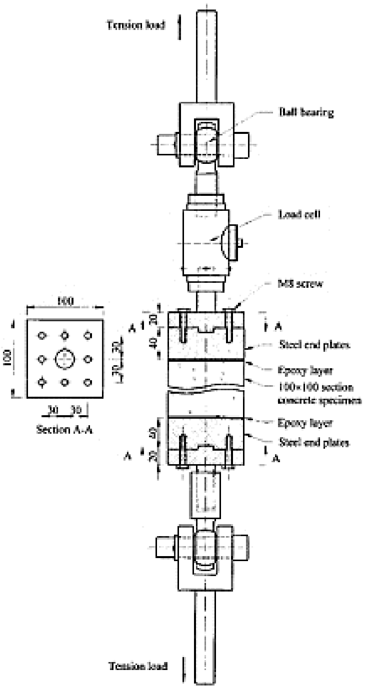

Fig. 2. Direct tensile testing device

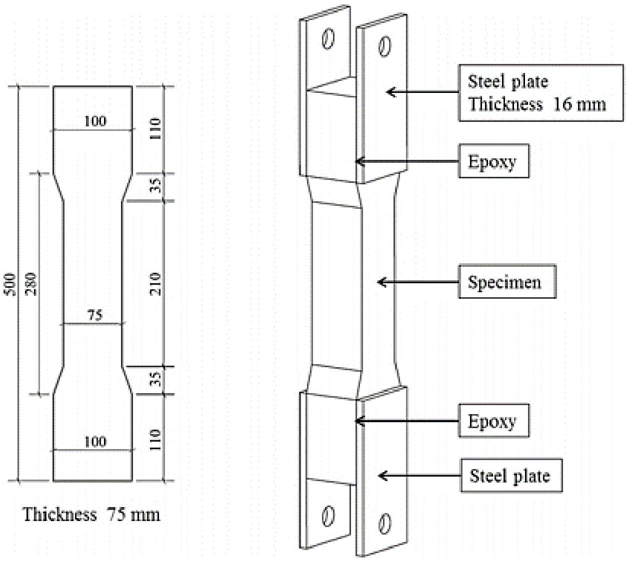

Fig. 3. Schematic diagram of direct tensile specimen

Kwan et al. [17] measured “the tensile stress-strain characteristics of fiber-reinforced concrete by applying tensile loads (Fig. 3) through laminated steel plates on the sides and spherical joints installed at the ends, thereby minimizing the stress in the specimen. Focus and avoid accidental bending due to misalignment. The results indicate that the first crack locations in the specimen are randomly distributed along the length of the central prismatic section without significant end effects. And from each stress-strain curve, two different tensile strain capacity values were obtained. One is defined as the tensile strain at the maximum stress, and the other is defined as the tensile strain when the tensile stress drops to 80% of the cracking stress. Extension strain. It was found that when the fiber factor is small, the tensile strain capacity remains very small, but when the fiber factor is increased high enough to achieve strain hardening, the tensile strain capacity increases significantly. And the correlation between the two definitions of tensile strain capacity and fiber coefficient and the strength ratio after cracking to the first cracking reveals that the strength ratio after cracking to the first cracking has a dominant effect and can therefore be used as a measure of the degree of strain hardening”.

3. COMPARISON OF ADVANTAGES AND DISADVANTAGES OF METHODS

Comparing the above tensile methods, it can be seen that axial tension is the most direct, objective and effective test method to test the tensile properties of concrete. It can truly reflect the tensile strength of the material and obtain the full uniaxial tensile stress-strain curve. In the axial tensile test, the steel fiber concrete specimen is subjected to uniaxial tension. By measuring the load and strain on the specimen, the tensile response can be directly obtained. At present, domestic and foreign scholars mainly use three loading methods to conduct uniaxial direct tensile tests: external clamping, internal embedded and bonding. In the actual loading process, no matter what loading method is used, the stress distribution of the specimen will be uneven during the test. Huang Jun [18] conducted a finite element analysis on three loading methods: external clamping type, internal type and bonded type. The analysis concluded that the two-end bonded loading method is more reasonable than the internal embedded and external clamp loading methods, both in terms of the stress uniformity inside the specimen and the degree of stress concentration generated at the contact point between the specimen and the external device.

4. CONCLUSION

In recent years, domestic and foreign scholars have conducted a large number of uniaxial tensile tests on SFRC using different methods, mainly including the external clamping dumbbell-shaped specimen method, the embedded steel bar method, the end bonding method and the side bonding method, etc., but there are still Some issues remain to be studied:

(1) When a traditional dumbbell-shaped specimen is subjected to a uniaxial tensile test, since the central part of the specimen is a square section and the sections near the two ends are rectangular sections, as the tensile load continues to increase during the test, the specimen The tensile stress at the position where the cross-sectional area becomes smaller will also suddenly increase, which will cause stress concentration at the variable cross-section of the dumbbell-shaped specimen, which will eventually lead to tensile failure here. According to the specification CECS13-2009 [19], this will lead to test failure.

(2) The embedded steel bar method and the externally clamped dumbbell specimen method have the same problem, both of which tend to cause local stress concentration at the end of the specimen, causing test failure.

(3) Although the end bonding method can ensure uniform distribution of end stress, this method is currently only applicable to plain concrete. For concrete containing fibers, especially steel fibers, the bridging between the fibers and aggregates will greatly increase the tensile load, which results in the bonding force between the test fixture and the specimen section being insufficient to support time damage, and it will be very difficult during the test. It is possible for the end face to debond from the test fixture, ultimately causing test failure.

(4) Kwan's side bonding method has largely solved the problem that fiber concrete is not suitable for end-face bonding methods. It is currently a method with a relatively high success rate for uniaxial tensile testing. This method proposes a new loading method for dumbbell-shaped specimens, which largely avoids stress concentration at the ends of the specimens. I think the side bonding method can also be applied to other prism specimens, because the sides of the prism also have a large enough bonding area to load the test device. Therefore, for other shapes of specimens, it may be a good uniaxial tensile method to apply tensile load through side bonding method.

The above summarizes the current uniaxial tensile testing methods of SFRC. Each method has certain limitations. There are still many possibilities for exploring the uniaxial tensile testing methods of SFRC.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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