Effect of Test Voltage and Age on the Resistivity of Carbon Fiber Reinforced Concrete

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Abstract. Using the four-electrode method, the resistivity of carbon fiber reinforced concrete (CFRC) with different fiber content and different curing ages was tested with different voltages. Starting from the relationship between fiber content, test voltage, curing age and resistivity, the conductive properties of CFRC were analyzed. The results show that: the greater the fiber content, the better the conductivity of CFRC; when the test voltage is greater than 15 V, the electrical resistivity of CFRC tends to be stable; the electrical resistivity of CFRC is closely related to the curing age.

Keywords. Carbon fiber, concrete, test voltage, age, resistivity.

1. Introduction
Compared with ordinary concrete, the mechanical properties and durability of CFRC are significantly improved [1, 2]. In addition, the conductivity of ordinary concrete is weak. In the dry state, the resistivity is about $10^7$-$10^9$ $\Omega \cdot m$, and in the saturated state, the resistivity is about $10^2$-$10^3$ $\Omega \cdot m$. However, the electrical conductivity of concrete after carbon fiber is mixed is significantly improved [3, 4], and its resistivity can be changed correspondingly with the change of external conditions. From this, good functional characteristics such as temperature sensitivity, pressure sensitivity, electric heating, electromagnetic shielding, etc. have been derived [5, 6].

In recent years, some research has been conducted on the electrical conductivity of CFRC. However, most studies have focused on the effects of carbon fiber content, carbon fiber length, water-cement ratio, sand rate, ambient temperature and humidity, and cyclic stress on the resistivity of CFRC [7, 8]. However, there are few studies on the resistivity of CFRC in terms of test voltage and age.

Based on this, this article uses the four-electrode method, and the CFRC with the fiber content of 0, 0.1%, 0.2%, 0.3%, 0.5% was tested at 1 V, 3 V, 5 V, 7 V, 10 V, 15 V, and 30 V on 1 d, 3 d, 7 d, and 28 d resistivity at maintenance age. The influence of fiber content, test voltage and age on the resistivity of CFRC is analyzed, which provides basic theoretical support for the research and application of carbon fiber smart concrete.
2. Experiment

2.1. Experiment Material and Mix Ratio
The raw materials required for the preparation of concrete specimens include: cement, aggregate, additives, water, ordinary 3 mm chopped carbon fiber. Cement: P·O42.5R cement. The basic parameters are shown in table 1. Aggregates include coarse aggregates and fine aggregates. Coarse aggregate: Limestone gravel of Jingyang County, with a particle size of 5-20 mm, a density of 2700 kg/m³, and a mud content of 0.2%. Fine aggregate: Bahe middle sand, fineness modulus is 2.78, graded lattice, density is 2630 kg/m³, and mud content is 1.1%. Additives include defoamers and water reducers. Defoaming agent: Tributyl phosphate defoaming agent. Water-reducing agent: FDN high-efficiency water-reducing agent produced by Guangzhou Jianbao New Building Materials Co., Ltd., brownish yellow powder. Water: tap water that meets testing standards. Carbon fiber: PAN-based 3 mm chopped carbon fiber produced by Toray Japan. The sample is shown in figure 1. The properties of the matrix are shown in table 2.

![Ordinary 3 mm chopped carbon fiber](image)

**Figure 1.** Ordinary 3 mm chopped carbon fiber.

| Brand       | Loss on ignition /% | Sulfur trioxide content /% | Magnesium oxide content /% | Initial setting time /min | Final setting time /h | Compressive strength /MPa |
|-------------|---------------------|-----------------------------|-----------------------------|---------------------------|-----------------------|--------------------------|
| Qinling Cement | ≤3.5               | ≤1.9-3.5                    | ≤3.0                        | 60                        | 5                     | ≥42.5                    |

| Carbon content /% | Young's modulus /GPa | Tensile strength /MPa | Resistivity /Ω cm | Density /kg·m³ | Monofilament diameter /μm | Elongation at break /% |
|-------------------|----------------------|-----------------------|-------------------|----------------|--------------------------|------------------------|
| 95                | 228                  | >3500                 | 1.0-1.6           | 1780           | 7                        | 1.5                    |

The volume ratio mass of concrete is shown in table 3. Among them, the number PC represents a common concrete specimen without carbon fiber, which is a reference group specimen. CFRC01,
CFRC02, CFRC03, and CFRC05 represent CFRC specimens with carbon fiber volume contents of 0.1%, 0.2%, 0.3%, and 0.5%, respectively.

Table 3. Volume ratio mass of concrete (kg/m$^3$).

| Specimen number | Water-cement ratio | Carbon fiber | Cement | Water | Gravel | Sand | Water reducer | Defoamer |
|-----------------|-------------------|--------------|--------|-------|--------|------|---------------|----------|
| PC              | 0.36              | 0            | 495    | 180   | 1008   | 672  | 0             | 0        |
| CFRC01          | 0.36              | 1.78         | 495    | 180   | 1008   | 672  | 5.0           | 0.30     |
| CFRC02          | 0.36              | 3.56         | 495    | 180   | 1008   | 672  | 7.5           | 0.45     |
| CFRC03          | 0.36              | 5.34         | 495    | 180   | 1008   | 672  | 10.0          | 0.60     |
| CFRC05          | 0.36              | 8.90         | 495    | 180   | 1008   | 672  | 15.0          | 0.90     |

2.2. Specimen Preparation
The preparation of ordinary concrete and nano-CFRC are based on the "sand-wrapping method", and the specific process is shown in figure 2. Put the fresh concrete into the steel mold, and then vibrate on the vibration table. Place the specimen in the room for 24 h, and then remove the mold. Carry out standard curing of the prepared specimen. Because the resistance needs to be tested, the electrode needs to be embedded before the test piece is poured. In this test, the electrode uses a single wire 1 mm diameter copper mesh. The size of the test piece is a rectangular parallelepiped of 100 mm×100 mm×400 mm, as shown in figure 3.

Figure 2. Flowchart of "Sand Wrap" for Ordinary Concrete and CFRC (a) ordinary concrete, (b) CFRC.

Figure 3. Concrete specimen.
2.3. Experiment Plan
A four-electrode method was used to test the resistivity of concrete specimens. The test diagram is shown in figure 4. The resistivity of the test piece can be calculated by the following equation:

\[ R_0 = \frac{U_0}{I_0} \]  

(1)

\[ \rho = \frac{R_0 A}{L} \]  

(2)

During the test, a voltage-regulated power supply with adjustable voltage is used as the voltage output. The two universal meters separately test the voltage and resistance between the electrodes. The actual measurement diagram is shown in figure 5.

![Figure 4. Test diagram.](image1)

![Figure 5. Measured map.](image2)

To study the influence of test voltage and age on the resistivity of CFRC, different ages (1 d, 3 d, 7 d, 28 d) and different fiber dosages (0, 0.1%, 0.2%, 0.3%, 0.5%) at different voltages (0, 3 V, 5 V, 7 V, 10 V, 15 V, 30 V) CFRC were resistivity tested.

3. Results and Analysis

3.1. The Effect of Fiber Content on the Resistivity of Concrete
Figure 6 is the 28-day-old carbon fiber-reinforced concrete, under the test voltage of 1 V, 10 V, 15 V, 30 V, the change rule of fiber content and resistivity. It can be seen that as the fiber content increases, the resistivity of CFRC shows a downward trend. The greater the fiber content, the lower the resistivity of CFRC, the stronger the electrical conductivity. When the fiber content is small, the resistivity of CFRC decreases significantly. At a test voltage of 30 V, when the fiber content is 0.1%, the CFRC has a resistivity of 103.96 Ω·m, a decrease of 20.92%. At a test voltage of 1 V, when the fiber content is 0.1%, the decrease in resistivity of CFRC is only 9.93%. When the fiber content is 0.5%, the resistivity of CFRC at 1 V, 10 V, 15 V, and 30 V test voltages is 98.77 Ω·m, 89.76 Ω·m, 87.9 Ω·m, 86.08 Ω·m.
Figure 6. The relationship between the fiber content and the resistivity of CFRC at the test voltages of 1 V, 10 V, 15 V, and 30 V at 28 days of age.

3.2. Effect of Test Voltage on the Resistivity of Concrete

Resistivity is an important physical index that characterizes the electrical conductivity of concrete. It is an important prerequisite for studying the functional properties of CFRC to select a suitable measurement voltage to accurately measure the electrical resistivity of CFRC. Figure 7 shows the variation of test voltage and resistivity of CFRC at 28 days of age. It can be seen that whether it is ordinary concrete or CFRC, the resistivity decreases with the increase of the test voltage. For the same set of concrete specimens, when the test voltage is 1 V, the resistivity is the largest; when the test voltage is 30 V, the resistivity is the smallest. When the test voltage is less than 15 V, the resistivity of the concrete specimen changes significantly; when the test voltage is greater than 15 V, the resistivity of the concrete specimen gradually flattens. When the fiber content is 0.5%, the resistivity of CFRC at 30 V test voltage is 97.93% at 15 V test voltage. Under any test voltage, when the fiber content is 0.2%~0.3%, the resistivity of CFRC decreases the most, the resistivity can decrease by a maximum of 12.52 Ω·m, and the maximum decrease is 10.25%. When the fiber content is 0.3%, the resistivity of CFRC at the test voltages of 1 V, 5 V, 10 V, and 30 V is 103.02 Ω·m, 98.44 Ω·m, 94.83 Ω·m, and 90.13 Ω·m, respectively.

Figure 7. The relationship between test voltage and resistivity of CFRC at 28 days of age.
3.3. Effect of Age on the Electrical Resistivity of Concrete

Figure 8 is the change rule of age and resistivity of CFRC at a test voltage of 15V. It can be seen that the resistivity of ordinary concrete and CFRC increases continuously with age. At any age, ordinary concrete has the largest electrical resistivity, and the CFRC with 0.5% fiber content has the smallest electrical resistivity. The resistivity of the concrete specimen increased rapidly during the 7-day age, and the resistivity increased slowly during the 7-28 day age. Figure 9 shows the increase in resistivity in the age range of 0–1 d, 1 d–3 d, 3 d–7 d, 7 d–28 d of CFRC at 15 V test voltage. It can be seen that the difference in resistivity growth value of ordinary concrete and CFRC with different fiber content is large within the age range of 0–1 d and 1 d–3 d. Within the age range of 3 d–7 d and 7 d–28 d, the difference in resistivity growth value is not large. And the increase of resistivity in the age range of 0–1 d, 7 d–28 d is larger than that of other ages.

![Figure 8. Relationship between CFRC resistivity and age at 15 V test voltage.](image)

![Figure 9. Relationship between age range and resistivity growth value of CFRC at 15 V test voltage.](image)

3.4. Mechanism Analysis

CFRC can be regarded as a composite material, carbon fibers with good electrical conductivity are used as the dispersed phase, and concrete is used as the matrix phase. The electrical conductivity of concrete consists of two parts, one part is completed by chopped carbon fiber filaments distributed in it, and the other part will be completed by the concrete matrix phase. Carbon fiber has more than 95% carbon content and has excellent electrical conductivity. The conductivity of the concrete matrix phase can be divided into ionic conductivity and electronic conductivity. Concrete materials mixed with an appropriate amount of chopped carbon fiber wire will produce good electrical conductivity, and its electrical resistivity will be greatly reduced compared with ordinary concrete. And the higher the fiber content, the better the conductivity of concrete and the lower the resistivity.

When the external voltage is low, especially below 15 V, the potential difference between the two ends of the test block is too small, the corresponding electric field strength is also relatively low, and the directional movement of ions and electrons is not easy, resulting in a large change in the measured resistivity. When the external voltage is above 15 V, the external electric field strength of the concrete specimen is sufficiently large at this time, and the ions and electrons can produce stable directional movement. At this time, the current is relatively stable, and the change in resistivity obtained by the test tends to be gentle.

CFRC has a complex hydration reaction during the curing period. In the initial stage of curing, the cement structure caused by the hydration of cement was not completely formed, and there were many penetrating passages inside the concrete to provide a good conductive environment for ions, so the resistivity increased rapidly. With the development of the hydration process, free water gradually decreased and the gel structure continued to develop, resulting in the gradual decrease in ion
concentration, the blocking of conductive pathways, and the increase in resistivity slowly until it stabilized.

4. Conclusion
(1) The fiber content has a great influence on the resistivity of CFRC. The larger the fiber content, the smaller the CFRC resistivity and the better the electrical conductivity.
(2) When the test voltage is small, the resistivity of CFRC changes greatly and is unstable; when the test voltage is greater than 15 V, the resistivity of CFRC tends to be stable.
(3) The resistivity of carbon fiber-reinforced concrete is closely related to the curing age. The resistivity increases rapidly in the early stage of curing, and slowly increases and stabilizes in the later stage.

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