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The experimental study on the correlation of resistivity and damage for conductive concrete

Hong-yan Chu [a], Jian-kang Chen [a, b, *]

[a] *The Faculty of Mechanical Engineering and Mechanics, Ningbo University, Ningbo, China*
[b] *State Key Laboratory of Turbulence and Complex Systems, Peking University, Beijing, China*

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ABSTRACT

This paper investigates the correlation of conductivity and damage evolution in carbon fiber reinforced conductive concrete. Under axial static loading and quasi-static cycle loading, the damage evolution is detected by ultrasonic technique, and the variation of resistivity is also inspected using real-time measurement method. According to the stress wave theory, the relationship between the damage evolution in concrete and variation of ultrasonic velocity is obtained, eventually concluding in the correlation of concrete damage and its resistivity. The research results indicate that concrete real-time damage and resistivity exhibits cubic polynomial correlation under the condition of a static load, and concrete resistivity and residual damage shows exponential growth rule under the condition of a cyclic load.

1. Introduction

Carbon fiber reinforced conductive concrete (CFRCC) exhibits an evident piezoresistive effect [1,2], which has led to a research hotspot regarding carbon fiber modification [3–5]. Many researchers have focused their studies on conductive concrete. For instance, Chen et al. studied a electronic properties of carbon fiber cement composites, and achieved the correlation between load and resistivity [6]. Subsequently, Wen et al. investigated the correlation between the longitudinal and transverse resistivity of cement mortar and the applied load under the condition of single axial compression. That research revealed that the resistivity of cement mortar in elastic range exhibited a reversible augmentation in longitudinal and transverse directions [7]. However, their research examined only a single dimensional stress state. Wu et al. studied the correlation between the resistivity in three directions of carbon fiber reinforced cement mortar composite material and the external load under bi-axial compression. Their research indicated that the piezoresistivity ratio of this composite material under bi-axial compression was more sensitive than under single compression [8]. Wen investigated the self-induction characteristic of material damage in carbon fiber reinforced conductive cement materials under single compression, and disclosed the irreversible phenomena in longitudinal and transverse resistivity of carbon fiber reinforced cement [9]. Based on the perspective that damage was the cause of the irreversibility, as opposed to elastic strain leading to the reversibility of concrete resistivity, some investigators proposed a new approach to test damage in carbon fiber reinforced cement composites through measuring resistivity [10,11]. Yun et al. studied the applicability of acoustic emission techniques to monitor damage evolution of carbon fiber reinforced concrete beam [12]. Hallaji and Pour-Ghaz developed a sensing skin for qualitative damage detection in conductive concrete [13]. However, these two detecting techniques were rather difficult to instruct in practice.

As for the application of piezoresistivity, Chen et al. proposed to test the internal damages of CFRCC using the resistivity measure method as well as the acoustic emission method, and verified the accuracy of the first method through the acoustic emission method [14]. In addition, the research performed by Sun et al. indicated that CFRCC possessed not only self-induction in stress and strain but also temperature sensitivity characteristics; however, its response velocity to temperature was slow [15]. Although numerous studies have been associated with the piezoresistivity of CFRCC, there is no published research on the correlation between CFRCC damage and its resistivity. In fact, the service life of concrete is closely correlated

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[*] Corresponding author. Ningbo University, Fenghua Road 818, Ningbo, Zhejiang, China.

E-mail address: chenjiankang1957@163.com (J.-k. Chen).

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with its damage evolution. There are various empirical models demonstrating the damage evolution of concrete (such as H-J-C model [16] and RHT model [17]); however, it is still a challenge to directly assess the real-time damage of concrete.

This paper investigated the correlation of conductivity and damage evolution for concrete with different contents of carbon fiber. When this type of carbon fiber composite material was subjected to axial static compression and quasi-static cyclic compression loads, concrete specimens were concurrently tested using ultrasonic inspection and resistivity measurement to obtain the variations of resistivity and ultrasonic velocity. In the end, a relationship between modulus-wave velocity and damage-wave velocity was derived to demonstrate the correlation of concrete damage and its resistivity.

2. Materials

2.1. Carbon fiber

T300 carbon fibers (produced by Changzhou Leade New Materials Co., Ltd) with cut length 20 ± 1 mm were prepared and used as conductive fillers in concrete, and the parameters of carbon fiber were shown in Table 1 below.

2.2. Concrete composition

Cement used in concrete was ordinary portland cement, the mineral components were listed in Table 2. Sand used in concrete was river sand, which fineness module was $Mx = 2.69$. Aggregate was gravel, which size was in the range of 5–16 mm.

2.3. Concrete constituents

The mix of specimens was chosen as: water to cement ratio: 0.5; cement: 435 (kg/m^3); medium sands: 533 (kg/m^3); gravel: 1242 (kg/m^3). Otherwise, carbon fibers were added into the mix. For convenient, specimens were numbered by symbols, C1, C2, …, C8, which denoted different volume fraction of carbon fibers, 0.1%, 0.3%, …, 1.5%, respectively.

To obtain a homogenous mixture, carbon fibers were dispersed carefully by hand, and then they were mixed with cement, medium sands, and gravel using a mixer for 5 min, after that these dry materials were mixed with water in the mixer for another 5 min.

The prepared concrete specimens (shape: cubic; size: 150 × 150 × 150 mm) were cured 24 h at ambient condition, after which point they were placed into concrete standard compartments for curing over a span of 28 days with a temperature of 21 °C and relative humidity of 95%.

3. Experimental methodology

3.1. Measurement of concrete resistivity

When dielectric material is exposed to an electric field, electric polarization will occur. Electric polarization refers to the phenomenon that the centers of positive and negative charges do not coincide [18]. There is also an electric field during electrical resistance measurement, so electric polarization will occur in a CFRCC during electrical resistance measurement. Electric polarization can induced electric field in the CFRCC being opposite in direction from the applied electric field, which causes the measured resistance to increase with time during resistance measurement. Thus, it needs a long time to obtain a stable resistance value of CFRCC. Because water content has a significant impact on the electric polarization of concrete specimens, this experiment was designed to control the water content in various specimens to an identical level through the following methods. After standard curing, concrete specimens were dried at in a room ambient environment for 20 days. It should be pointed out that the water loss varies for different type specimens due to different porosity, however, it does not change much. The detected results shows that the water loss ratio for the final concrete specimens was 5 ± 0.1% weight of the cured specimens. Otherwise, different moisture gradient would be formed inside the concrete specimens because of different porosity, and it may affect the distribution of the initial resistivity and the initial average resistivity of specimens [19,20]. However, once the initial average resistivity is determined, its variation under loading would be dominantly caused by the deformation or damage evolution. Hence, this study will focus on the correlation between variation of average resistivity and damage evolution by ignoring the effect of moisture gradient. For convenience, such an average resistivity will be called resistivity in the following.

A TG2302-5 electrical resistance-measuring instrument was used to test the resistances of CFRCC. The four-electrode measuring method used in instrument could effectively improve the electrical resistance measuring precision. Measurement of static electrical resistance was shown in Fig. 1.

Because the electrical resistance R and resistivity of concrete ρ follows the equation below:

Table 2
Mineral components contained in cement.

Composition	C_3S	C_2S	C_3A	C_4AF	Blended gypsum
Magnitude (%)	55.700	19.200	6.3000	10.200	5.1000

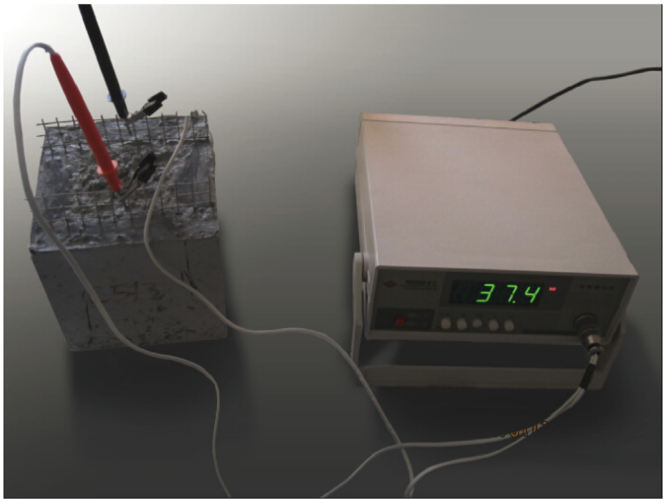

Fig. 1. Measurement of static electrical resistance.

Table 1
T300 carbon fiber properties.

Diameter (μm)	Density (kg/m^3)	Resistivity (Ω m)	Elastic modulus (GPa)	Poisson's ratio	Tensile strength (GPa)
7.2000	1760.0	3.0000×10^{-3}	230.00	0.33500	3.5300