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Effects of salt freeze-thaw cycles and cyclic loading on the piezoresistive properties of carbon nanofibers mortar

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HIGHLIGHTS

- Piezoresistivity evolution of CNFs mortar with freeze-thaw cycles was presented.
- NaCl accelerated the freeze-thaw cycles induced degradation of piezoresistivity.
- Cyclic loading before freeze-thaw cycles debased the piezoresistivity.

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ABSTRACT

This paper aims to investigate the evolution of electrical resistance and piezoresistivity of carbon nanofibers (CNFs) mortar with freeze-thaw cycles in solutions containing 0%, 1.5% and 3.0% NaCl. Two temperature ranges selected for the freeze-thaw cycles are −10 °C to 10 °C and −20 °C to 20 °C respectively. Four groups of cement mortars with water to cement ratios (w/c) of 0.5, 0.45, 0.4 and 0.35 were prepared by incorporating 2.25% CNFs by cement volume. Additionally, cyclic loading damage was applied to selected samples before exposure to freeze-thaw cycles. Experimental results showed that the strain-sensing sensitivity and linearity of CNFs mortar with low w/c ratios were decreased by the freeze-thaw cycles under temperature of −10 °C to 10 °C. However, the samples with high w/c ratios exhibited an opposite tendency with freeze-thaw cycles. The higher concentration of NaCl solution induced the worse degradation of sensitivity and linearity of low w/c ratio samples. The salt freeze-thaw cycles under temperature of −20 °C to 20 °C resulted in the obvious degradation of piezoresistivity for all the samples. Moreover, the cyclic loading history before freeze-thaw cycles debased the sensitivity and linearity of strain-sensing property of CNFs mortars. Therefore, negative effects from both mechanical loading and freeze-thaw environment should be fully considered for the field application of this type of self-sensing material.

1. Introduction

It is well known that cement-based materials combined with conductive fillers can serve as self-sensing materials. These self-sensing materials are usually used to monitor the damage, stress, strain and displacement of concrete structures based on the fractional change of electrical resistance without the need of other sensors [1–3]. Conventional sensing devices such as fiber-optic sensors, strain gage and shape memory alloy are usually applied to the health monitoring of concrete structures. These methods have several disadvantages including a high cost for equipment, complicated installation and premature damage. On the contrary, self-sensing cement-based materials are characterized by simple preparation, embeddable and in-situ monitoring, long-term durability, high reliability and good compatibility with concrete structures [4–6].

As an elegant engineered material, carbon nanofibers (CNFs) present hollow cylinder with diameters of around 100 nm and lengths of a few microns. Compared with carbon nanotubes (CNTs), CNFs show numerous exposed edge planes along the surface, being advantageous to chemical or physical interaction. Moreover, CNFs are produced at a lower cost than carbon nanotubes (CNTs) [7]. Some researchers reported that CNFs cement-based materials behaved a good self-sensing ability [6,7], being able to well

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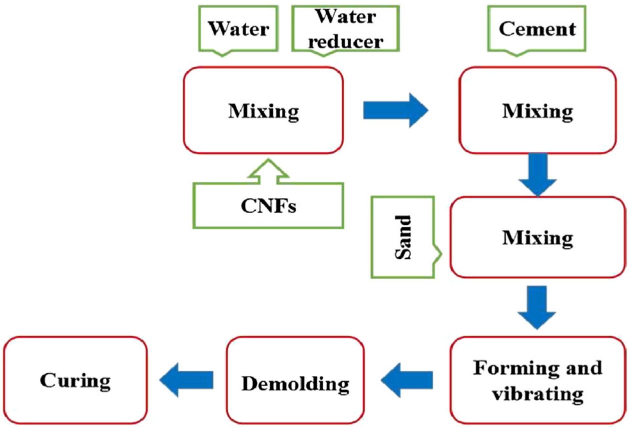

Fig. 1. The preparation process of mortar specimen.

Table 1
Freeze-thaw experiment conditions.

Types	Cyclic stress/Ultimate compressive strength	NaCl concentration
M1	0	0
M2	30%	0
M3	0	1.5%
M4	30%	1.5%
M5	0	3%
M6	30%	3%

responds to the applied stress, strain and damage by electrical resistance records [8]. CNFs cement-based materials can also be used in electromagnetic shielding [9], traffic monitoring and deicing [10,11]. Furthermore, CNFs cement-based material provides a possible method for diagnosing the damage status of concrete structures exposed to environmental or/and mechanical loading damage. This output signal provides a reliable basis for selecting suitable rehabilitation or self-healing plans [12].

Concrete structures are often exposed to freeze-thaw environment in some regions like the northern part of China. The freeze-thaw cycles may result in degradation of macro and micro structure and ion concentration variation of pore solution. The resistance and piezoresistivity of CNFs cement-based materials are influenced by ionic migration conduction, electric phenomena, electric polarization and macroscopic tunneling effect [13,14]. Therefore, the resistivity of CNFs cement-based materials will vary with freeze-thaw cycles and subsequently influence the piezoresistive performance [15]. On the other hand, salt freeze-thaw conditions exist for concrete structures of the pavement system due to the usage of deicing salts in winter and for those in marine regions [16]. Additionally, a real concrete structure always works under loading including its self-weigh action. The coupled effect of loading, salt and free-thaw cycles has an accelerating deterioration effect on CNFs cement-based materials and little studies have been carried out in this field.

This paper aims to study the influence of freeze-thaw cycles on electrical resistance and piezoresistive performance of CNFs mor-

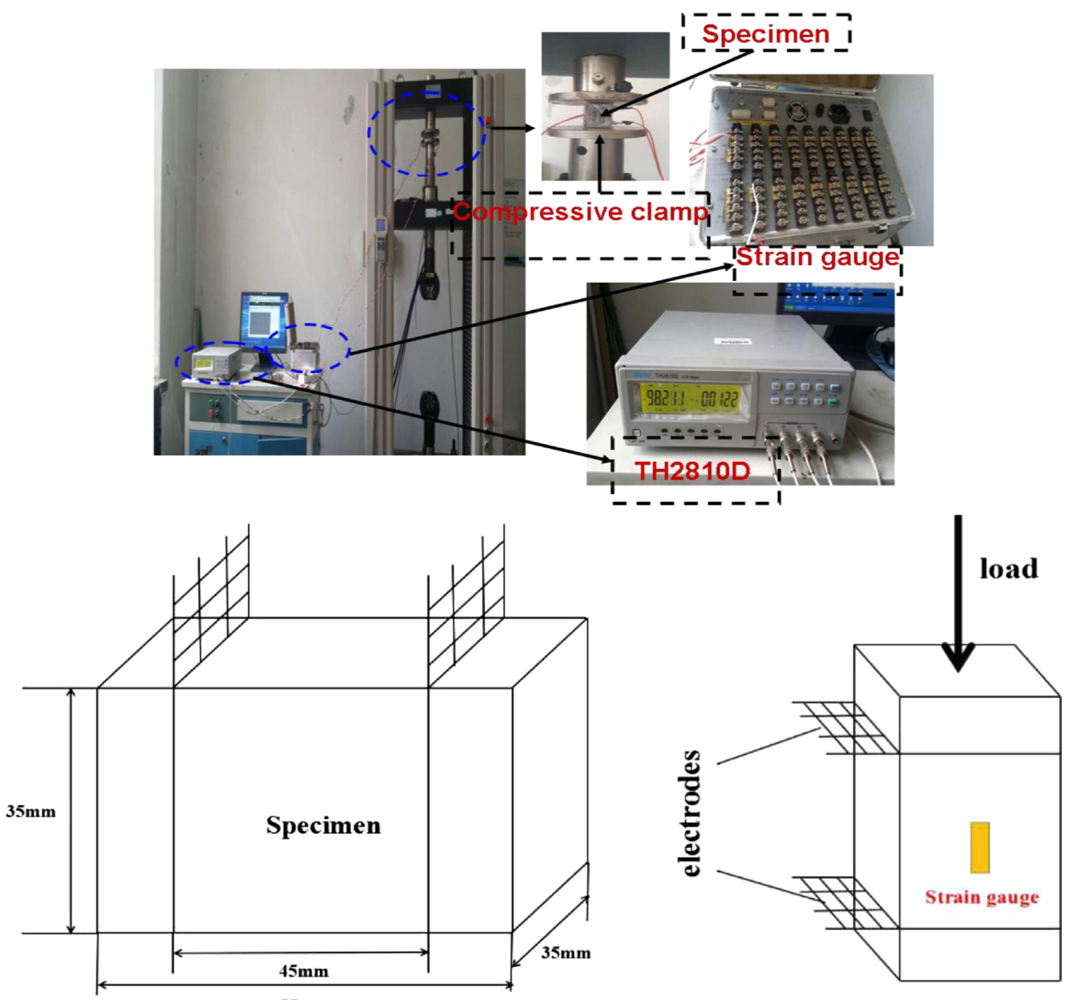

Fig. 2. The equipment for piezoresistivity measurement.