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Concrete damage diagnosis using electromechanical impedance technique

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HIGHLIGHTS

- An embedded piezoelectric sensor for damage diagnosis of concrete was developed.
- Freezing-thawing and crack damage of concrete were monitored.
- A mathematical method was proposed to evaluate the concrete damage development.

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ABSTRACT

Here an embedded piezoelectric sensor was fabricated to monitor the freezing-thawing and crack damage of concrete by using electromechanical impedance technique. The results show that the damage evolution of concrete is dependent on impedance spectra of the piezoelectric sensor. The resistance values of the sensor increase gradually with increasing the concrete freezing-thawing cycles and the crack depth under the same testing frequency interval. The root mean square deviation index was used to evaluate the damage extent of concrete. It increases with increasing the freezing-thawing cycles and crack depth, and shows a most obvious variation in the 100–150 kHz frequency intervals. This research shows that the concrete damage and its evolution can be effectively monitored by employing the embedded piezoelectric sensor based on the electromechanical impedance technique.

1. Introduction

With the reported increasing number of collapses occurring in major infrastructures, structural health monitoring (SHM) and nondestructive testing (NDT) of civil structures has become of significant importance. The use of smart materials capable of providing autonomous, real-time, reliable and cost effective monitoring is constantly being pursued by SHM engineers [1–3].

In the last decades, piezoelectric ceramic attracts researchers' attention due to its superior sensing and actuating properties, and the electromechanical impedance (EMI) active sensing technique based on piezoelectric sensor has also emerged as a potential tool for the implementation of a built-in online monitoring system of civil infrastructures [4,5]. Park et al. detected the bolted joint structure, civil structure component and built-in pipeline using EMI technique, and obtained the significant experimental results [6,7]. Soh et al. monitored the RC bridge using the impedance method, and provided a procedure to interpret a signal from debonding or breakdown of the PZT sensors [8]. Tseng et al. presented numerical studies in which surface-bonded impedance sensors were used to monitor two types of damage, void ad crack, in a concrete structure [9,10]. Many experimental investigations have been successfully performed on complex civil engineering structures due to the distinct advantages of EMI technique, such as the ability to detect incipient damage, use of non-intrusive transducers and potentially low-cost applications [11–15].

It is known that the freezing-thawing destruction and crack damage are two of the most important destroying factors of concrete structure. Therefore, it is significant to perform the online monitoring to interrogate the destructive location and extent of concrete structures. Here the Lead Zirconate Titanate (PZT) piezoelectric ceramic was used as sensing element to fabricate the embedded piezoelectric sensor, and the freezing-thawing and crack damage of concrete was investigated by analyzing the electric impedance variation of the piezoelectric sensors in different frequency intervals.

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2. Experimental process

2.1. Fundamentals of the electromechanical impedance technique

Piezoelectric materials are usually categorized as smart materials due to their direct and converse piezoelectric effects. The EMI technique is a tool for diagnosing the concrete damage in this research based on the piezoelectric effects. It is known that the mechanical impedance of structure will change when subjected to damage. When piezoelectric materials are coupled to structure, the piezoelectric materials will vibrate under effect of alternating electric field due to the converse piezoelectric effect, which thereby causes the vibration of the coupled structure. Therefore, it is possible to obtain the mechanical properties of the structure through the electric impedance response of piezoelectric materials [11]. The model of PZT-structure electromechanical interaction in 1D and 2D structure proposed by Liang et al. [16], Xu et al. [17] and Bhalla et al. [18] was shown in Fig. 1.

2.2. Preparation of PZT sensors

The PZT piezoelectric ceramic wafers of 10 mm × 10 mm × 2 mm were here employed as sensing element to fabricate the electromechanical impedance sensors. The shielded wires were welded on electrodes of the PZT wafers, and then a mixture of cement, epoxy resin and hardener was used to package the inside PZT elements according to a mass ratio of 1:1:0.3. The thickness of the packaging layer was about 1 mm to reduce its influence on EMI technique. The cement particles reinforced epoxy resin packaging material can not only improve the insulation capability of the PZT sensors, but also protect the inside PZT elements from damage in use. The packaged PZT electromechanical impedance sensors were shown in Fig. 2.

2.3. Freezing-thawing experiments

The concrete freezing-thawing and simulation crack damage experiments were conducted to verify the validity of the electromechanical impedance technique. The cubic concrete blocks of 100 × 100 × 100 mm containing PZT sensors were fabricated for the freezing-thawing experiments. After curing for 24 day, the concrete blocks were taken out from the curing chamber, and then were put into water of 15–20 °C for 4 days. The concrete blocks were then weighed after cleaning the surface water, and were put into the testing box with rubber bearings around them. It is noted that the top surface of the concrete block in the whole experimental process was 5 mm lower than the water level of the testing box. The concrete block in the testing box was put into the freezing thawing chamber for freezing and thawing cycle. The details of the freezing and thawing cycle were as followings. First, the cyclic process was completed in 2-4 h, and the thawing time was no less than the whole cyclic time. The center temperature of the concrete blocks after freezing and thawing was −17 ± 2 °C and 8 ± 2 °C, respectively. The freezing and thawing time of each block was no less than half of the whole freezing and thawing time, and the temperature difference between the interior and exterior blocks was less than 28 °C. Fig. 3 shows the concrete blocks after 25 and 50 cycles of freezing and thawing.

Fig. 2. The PZT electromechanical impedance sensors.

A total of 50 cycles of freezing and thawing were performed. The electric impedance of the PZT sensors were measured every 25 cycles, and the external damage check and weight loss calculation of the concrete blocks were also conducted.

2.4. Simulation experiment of crack damage

The concrete beam of 100 × 100 × 400 mm where the PZT sensors were embedded was fabricated to perform the simulation experiment of crack damage. The layout of the sensors in the concrete beam was shown in Fig. 4. The artificial crack of 5 ± 0.5 mm in width was produced by using the cutting machine, and the crack depth was 10 mm, 30 mm and 50 mm after each cutting. The electric impedance of the PZT sensors was measured by using the impedance analyzer for each crack depth.

In order to assure the resolution of EMI technique on damage identification of concrete structure, the refined testing frequency intervals were here considered, namely, 100–150 kHz, 150–200 kHz, 200–250 kHz, 250–300 kHz, 300–400 kHz and 400-500 kHz.

3. Results and discussion

3.1. Freezing-thawing damage analysis of concrete

Figs. 5 and 6 show the resistance vs. frequency spectra of the PZT sensors in two groups of freezing-thawing specimens at different frequency intervals, respectively. It can be seen that the

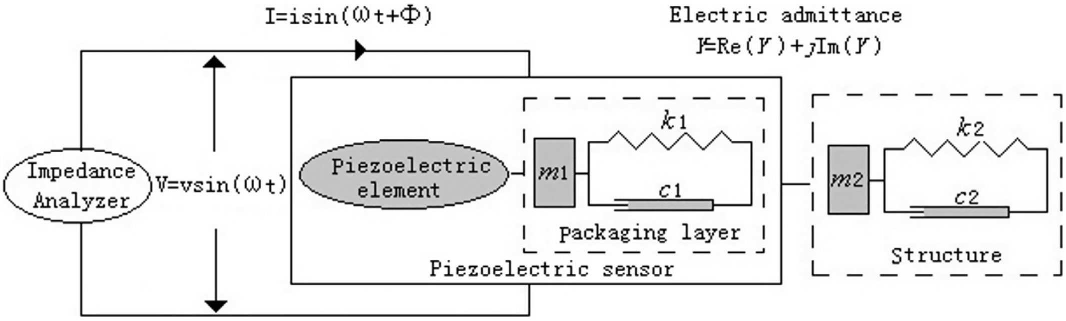

Fig. 1. One dimensional interaction model between piezoelectric sensor and structure.