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Research on the influence of ambient temperature on signal of piezoelectric smart aggregate transducer

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ABSTRACT

In recent years, piezoelectric smart materials are widely applied in the field of concrete structure damage monitoring. The characteristics of piezoelectric smart materials make it sensitive to the state change of concrete materials. Therefore, the health monitoring of concrete structures based on piezoelectric smart materials has been a research focus in the civil engineering. At present, PZT chip is often packaged as piezoelectric smart aggregate transducer. Some research results had shown that the performance of PZT chip is obviously affected by ambient temperature. In order to explore the internal relationship between PZT properties and ambient temperature, it is focused that its signal stability affected by temperature. And then, the cause of the signal stability is proposed. The research results in this paper show that the signal stability of piezoelectric smart aggregate transducer is affected by the ambient temperature. Its internal reason is that the elastic constant of the piezoelectric materials change with the temperature. The research results in this paper lay a foundation for further improving the theory of piezoelectric smart aggregate transducer and putting forward the temperature compensation method.

1. INTRODUCTION

In recent years, the health monitoring technology for concrete structures using piezoelectric smart aggregate (SA) transducer is received attention widely by scholars and engineers. It is a kind of low-cost transducer based on piezoelectric materials. It was first proposed by the American researcher (Song G 2006). The PZT chip is encapsulated by fine stone concrete, or marble, or mortar, forming SA which bearing capacity and volume are all similar to ordinary aggregate. And it has the dual functions of sensing and driving, which is suitable for the health monitoring of concrete structures. At present, the research on the health monitoring method of concrete structures using SA has been widely developed. (Song G 2006) used SA as a basic monitoring element and buried it into a “T” shape reinforced concrete beams for a health monitoring test.

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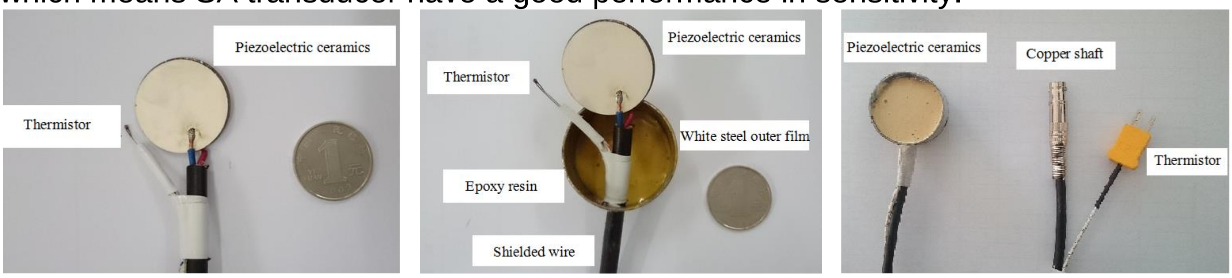
The result shows that SA can effectively monitor the process of structural damage increasing with the increase of load. (Gu H C 2010) used SA for damage monitoring of reinforced concrete columns under the dynamic load. The result shows that the damage index increases with the load level. (Yan Shi and Sun Wei 2009, 2010, 2012, 2014) had done a lot of researches using SA in monitoring kinds of reinforced concrete members including beams, plates, columns and shear walls etc. All the results show that the decaying of the monitoring signal energy is sensitive to the crack damage of concrete. It is suitable to be used as the characteristic parameter in the damage identification. In the tests, transducers array is also used to divide the components into several sub monitoring regions to gain damage localization information. Although a lot of research results had been gotten in the field, the concrete structure health monitoring method based on SA transducer is not mature really. The monitoring signal stability of SA is easily affected by ambient temperature. Therefore, it is necessary to explore the influence of ambient temperature on the signal stability of SA further. And the fundamental reason will be found out which cause the change of the temperature stability of the SA. The research result in the paper will lay the foundation for proposing the temperature compensation method of SA.

2. ENCAPSULATION AND SENSITIVITY CALIBRATION OF SA TRANSDUCER

The key components of SA transducer are PZT chip and thermocouple in this paper. The PZT chip enables SA have dual functions of sensing and driving. The thermocouple enables SA to monitor the ambient temperature. Epoxy resin is used as the packaging material, which enable SA to have good waterproof performance. The encapsulation process of the SA is shown in Fig.1. First, the PZT chip and the thermocouple are welded with the wire. Then, half of the epoxy resin is poured into the white steel tube. After the strength of epoxy resin gets to initial set, the sensors are put into the white steel tube, and another half epoxy resin is put into the steel tube. The sensors are sealed. When the epoxy resin is completely hardened, the SA transducer is formed. Besides used as the mold of SA, the white steel tube also can shield noise when SA is in the use stage. It increases the signal quality of SA.

To test the sensitivity of intelligent aggregate, the force hammer, charge amplifier and digital oscilloscope are used as test devices, as shown in Fig.2. The SA is knocked the by the force hammer, and the percussion force produced on the force hammer is converted into the output voltage signals by the force hammer and the SA, which are amplified by the charge amplifier and then displayed on the digital oscilloscope. As shown in Fig.3, the sensitivity of the SA transducer made by this process is about 0.67, which means SA transducer have a good performance in sensitivity.



(a) (b) (c)

Fig. 1 The schematics of the core part of the new packaged SA

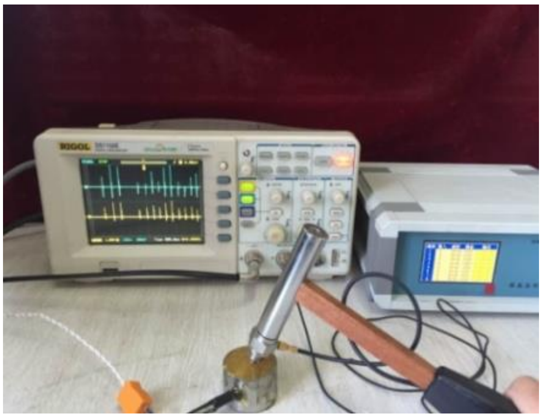


Fig. 2 SA sensitivity test

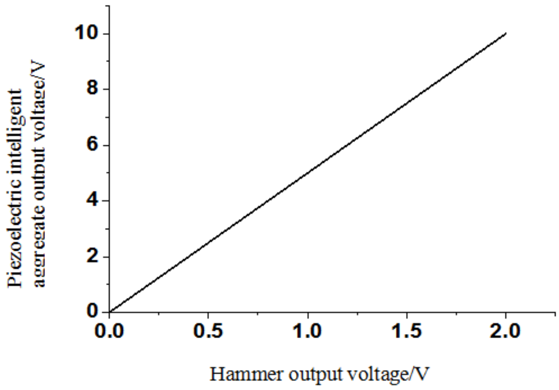


Fig. 3 SA sensitivity

3 TEMPERATURE STABILITY TEST OF SA TRANSDUCER

3.1 Test Introduction

To research the signals changing law of SA transducer with the ambient temperature is the basis to propose temperature compensation method further. In this paper, a test method is used to learn it. In the test, PZT-4 is used as the sensing element of SA, and its parameters are shown in Table 1. A pair of SAs are embedded in a concrete beams to transmit and receive monitoring signals. The size of concrete beams and the positions of SAs in the beam are shown in Fig.4. The data acquisition equipments include function generator, signal amplifier, digital oscilloscope and electronic multimeter, as shown in Fig.5. In the test, the sine wave is used as the detection signal, which the amplitude is set to 10V, and the frequency is 1kHz. The magnification of the signal amplifier is 15 times.

A temperature cabinet is used to simulate change of ambient temperature, which working room size is 500mm×500mm×600mm, and its working temperature range is -30℃ ~ 120℃. In the test, the concrete beam is placed into the temperature cabinet, and the temperature range is set from -30℃ to 45℃.Test signals are collected at 15℃ interval. So there are six temperature nodes in the test. When the temperature in the device reaches each temperature node and is stable, about 30~50 signals will be collected.

type	size mm	Piezoelectric constant 10^{-12}c/N	Capacitance pF	density $Kg\cdot m^{-3}$	Dielectric loss %	Electromechanical coupling coefficient
PZT-4	φ20×1	350	4500	7450	0.3	0.59

Table 1 PZT-4 ceramic piezoelectric parameters

Fig.4 Dimension of concrete specimen

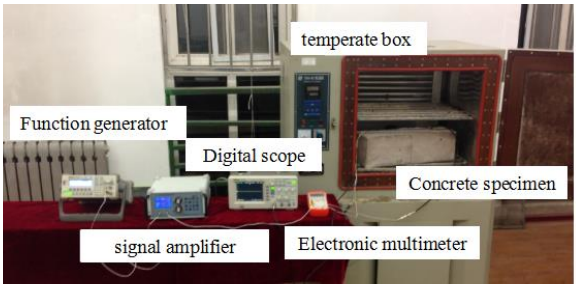


Fig.5 Experimental setup

3.2 Analysis of Test Phenomena

The SA in the left of the concrete beam is used as a signal emission sensor to transmit signals, and the one in the right end is used as a signal reception sensor to receive signals, as shown in Fig.4. Comparison of sinusoidal signal waveforms received by SA at each temperature node is shown as in Fig.6. It can be seen that the amplitudes of sinusoidal signals received by SA increase with the temperature when the emission signals are the same. This indicates that temperature has obvious influence on the signal transmitting and receiving performances of SA. The relationship between signal amplitude and temperature is established and shown in Fig.7. It can be seen from the figure that the amplitudes of sinusoidal signal increases linearly with the increase of temperature when the ambient temperature under 30℃. The amplitudes of sinusoidal signals tends to be gentle with increasing temperature when it over 30℃.

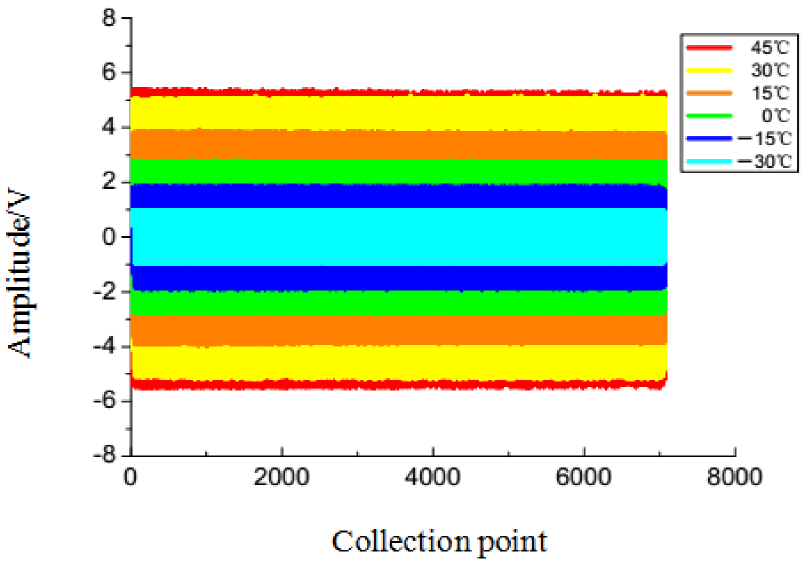


Fig.6 sine wave changes with ambient temperature

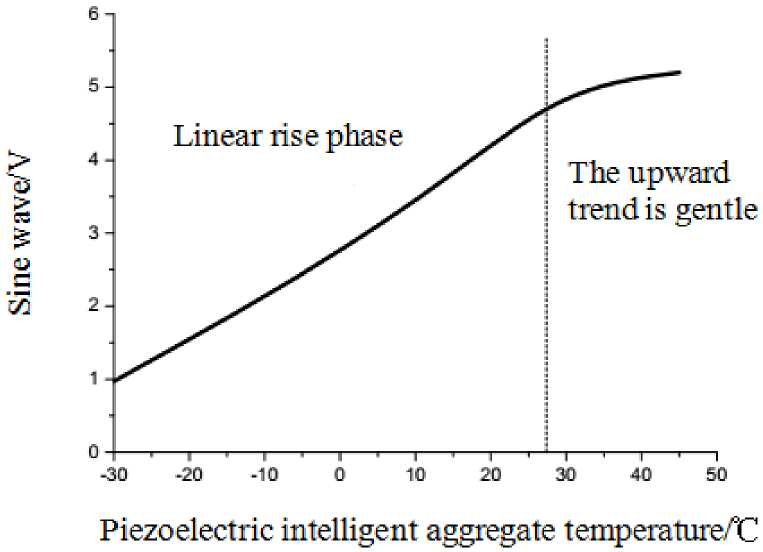


Fig.7 signal amplitude changes with ambient temperature

4. CAUSE ANALYSIS OF TEMPERATURE SENSITIVITY OFSA TRANSDUCER

The electromechanical coupling coefficient is an important parameter to reflect the electromechanical conversion efficiency of piezoelectric materials. It can be expressed as the square root of the ratio of the energy stored in the piezoelectric body to the total energy of the input in the form of mechanical energy, or the square root of the ratio of the energy stored in the piezoelectric body to the total energy input in the form of electricity. The test results in this paper show that the ambient temperature change affects the amplitude of signals received by SA transducer. It is essence that ambient temperature change affects the electromechanical conversion ability of piezoelectric material, which is the electromechanical coupling coefficient. Precious research; (Wang T B 1981) have showed that, there are intrinsic connections between the electromechanical coupling coefficient of piezoelectric material and its elastic constant, piezoelectric constant, and dielectric constant. Among those constants, the elastic constant dominates electromechanical coupling coefficient. And it is also a temperature dependent physical quantity. The influence of temperature on the properties of piezoelectric material is related to the binding ability of atoms or molecules in piezoelectric ceramic crystals to electrons.

When the temperature becomes higher, the kinetic energy of the electrons increase which make them easier to get rid of the constraints of atoms or molecules (Sun K 1986). Thus, the elastic constants increase. In the literature, the elastic stiffness coefficient is calculated by the formula (1). It is temperature h expansion series:

$$c_{ij} = c_{ijo}[1 + h^{(1)}_{cij}(h - h_0) + h^{(2)}_{cij}(h - h_0)^2 + h^{(3)}_{cij}(h - h_0)^3] \tag{1}$$

Formula (1) is called the equation of elastic temperature characteristic. Where the $h^{(1)}_{cij}$, $h^{(2)}_{cij}$, $h^{(3)}_{cij}$ are temperature constants of elastic constants of level 1, level 2, level 3 respectively.

The curve shown in Fig.8 is the temperature dependence of the electromechanical coupling coefficient of PZT-4 material provided by Sensor Technology Limited. It can be seen from the curve that the electromechanical coupling coefficient of PZT-4 material increases approximately linearly with the increase of temperature under 35℃. When the temperature reaches 35℃, the electromechanical coupling coefficient reaches the maximum. Subsequently, the electromechanical coupling coefficient slowly decreases with increasing temperature. The trend of the electromechanical coupling coefficient with temperature in Fig.8 is consistent with the trend of the signal amplitude with temperature in the test results of this paper; which proves the correctness of the results in this paper.

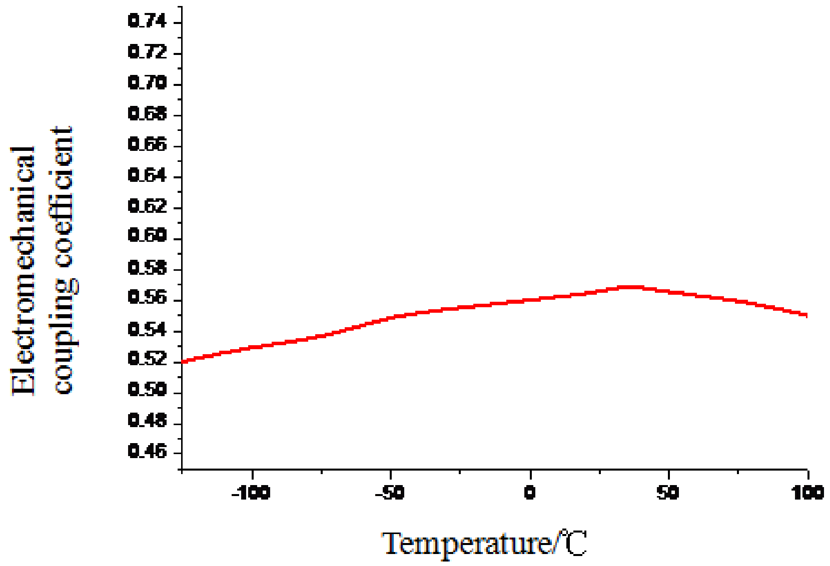


Fig. 8 The curve of electromechanical coupling coefficient of piezoelectric ceramics with temperature

5. CONCLUSIONS

In this paper, a test about the temperature stability of SA transducer is conducted. The following conclusions are drawn:

(1) The signal stability of SA transducer is obviously affected by temperature. The signal amplitude increases linearly with temperature when the ambient temperature under 30℃. The amplitude of sinusoidal signal tends to be gentle with increasing temperature when it over 30℃.

(2) The fundamental reason for the temperature stability of SA transducer is that the elastic constants of piezoelectric ceramics are correlated with the temperature. The elastic constants of piezoelectric ceramics are the decisive factors of their electromechanical coupling coefficients.

(3) The change trend of electromechanical coupling coefficient with temperature is consistent with the temperature stability of SA.

Therefore, the temperature stability of SA transducer can't be ignored when it is applied in the engineering. The theory presented in this paper should be a foundation to propose the method of temperature compensation of SA transducer further.

ACKNOWLEDGMENTS

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