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Monitoring hydration characteristics of cement paste by EMI method

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ABSTRACT: A monitoring system, which employs a piezoelectric ceramic as an active sensing transducer, is proposed for monitoring hydration characteristics of cement paste based on the electromechanical impedance (EMI) method. An impedance analyzer was used to obtain the electrical response of the sensor and the EMI measurements were performed by an online technique. The obtained data were analyzed using root mean square deviation (RMSD), a common statistical algorithm used for comparative processing of EMI spectra. The results show that the developed monitoring system is able to effectively detect physical changes of cement paste during the initial hydration.

1 INTRODUCTION

Many studies have been reported on understanding the hydration process of cement-based materials (e.g. Hansen et al. 1973, McCarter & Afshar 1985, Struble et al. 1998). In recent years, attention has been directed towards monitoring of hydration of cement from fresh state to hardened state by automated or online techniques (De Schutter et al. 2006, Rajesh et al. 2007, Poursaee & Weiss 2010). In a conventional approach, the setting time of cement paste can be manually determined from the penetration test in accordance with ASTM C191.

This work focuses on the relatively new nondestructive approach known as electromechanical impedance (EMI) method using piezoelectric active transducers. So far only one work (Divsholi & Yang 2009) has been reported on monitoring initial hydration of concrete based on the EMI method. The prime objective of this research is to develop a more effective and efficient monitoring system that could be used for field application.

2 ELECTROMECHANICAL IMPEDANCE METHOD

The EMI sensing technique has been demonstrated successfully for monitoring damages in structures (e.g. Park et al. 2001, Soh et al., 2000, Naidu & Bhalla 2002, Park et al. 2006). The basis of the EMI method is basically to monitor variation in mechanical impedance of a structural element via electrical impedance of a piezoelectric sensor bonded to or embedded in the host structure. The piezoelectric behavior is governed by the following relations (Ikeda 1990):

$$D_3 = \bar{\varepsilon}_{33}^T E_3 + d_{31} T_1 \tag{1}$$

$$S_1 = \frac{T_1}{\bar{Y}^E} + d_{31} E_3 \tag{2}$$

where D_3 and E_3 are the electrical displacement and field, respectively, acting along axis '3', T_1 and S_1 are the axial stress and strain, respectively, in the direction of axis '1', $\bar{\varepsilon}_{33}^T$ is the complex electric permittivity at constant stress, d_{31} is the piezoelectric strain coefficient and $\bar{Y}^E$ is the complex Young's modulus of elasticity of the piezoelectric material at constant electric field.

3 EMI MEASUREMENT

Figure 1 shows the schematic diagram of the monitoring system. It consists of a developed reusable sensor with bonded PZT plate, an impedance analyzer (Agilent 4294A) and a laptop equipped with data acquisition software.

The EMI measurement is conducted by measuring the electrical impedance of the bonded PZT at frequency range nearing its resonance. In this study, the measurement was taken at 15-min intervals for the 24 hours of curing of the cement paste specimen. To ensure repeatability of the reusable sensor, three batches of the same mix proportion were prepared.

4 RESULTS AND DISCUSSION

Figure 2 shows samples of the measured real parts of PZT impedance at selected monitoring time. It can be seen in Figure 2 that the resonance peak reduces and shifts to the right as time passes by.

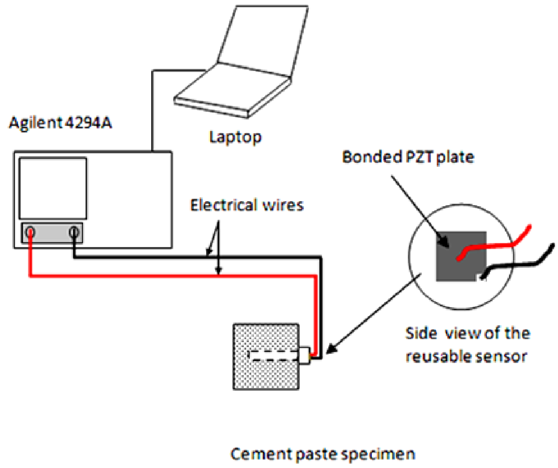

Figure 1. Schematic diagram of the monitoring system.

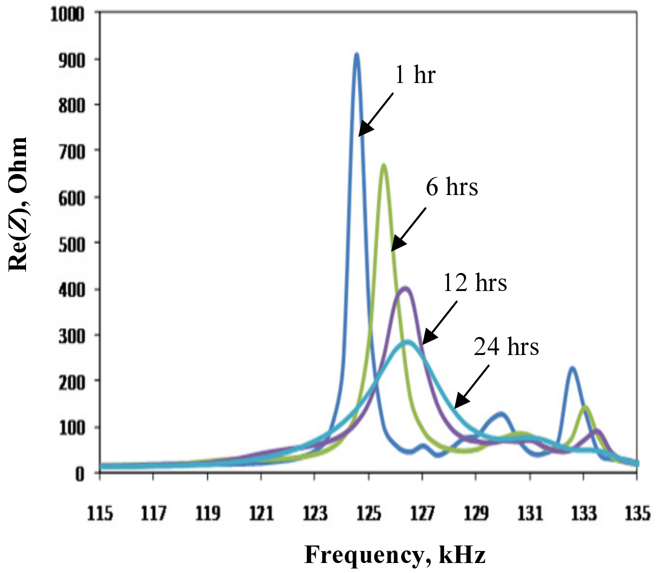

Figure 2. Samples of Re(Z) spectra at 1, 6, 12 and 24 hours.

The changes in the Re(Z) spectra were analyzed using root mean square deviation (RMSD) as follows:

$$RMSD = \sqrt{\frac{\sum_{i=1}^{N}[\mathrm{Re}(Z_i^1) - \mathrm{Re}(Z_i^0)]^2}{\sum_{i=1}^{N}[\mathrm{Re}(Z_i^0)]^2}} \qquad (3)$$

where $\mathrm{Re}(Z_i^0)$ is the baseline value of the ith frequency point at initial curing and $\mathrm{Re}(Z_i^1)$ is the value of the ith frequency point of the subsequent monitoring time. N is the upper limit of the frequency range.

In general, the RMSD value increases as the change in the Re(Z) spectra becomes larger. The change in the RMSD value can be used to monitor the characteristics of the cement paste during hydration process.

5 CONCLUSION

This study presents an EMI piezoelectric based method to investigate the hydration of cement paste. The results show that the physical changes of cement paste during hydration can be monitored by comparative processing of the change in the Re(Z) spectra. The reusable sensor, which can be easily detached from the specimen, is efficient for repetitive monitoring and hence would be practical for field application.

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