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Setting determination for cement-based material using embedded piezoelectric transducers

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ABSTRACT

In this research, transducers made of piezoelectric ceramic were embedded into fresh concrete to monitor the hydration process. The piezoelectric transducers were used to generate and receive ultrasonic waves. The amplitude of the received waves was analyzed. Compared with penetration test result, it was found that the development of wave amplitude could determine the initial and final setting points.

1. INTRODUCTION

Cement is one of the most important structural engineering materials. It's hydration and hardening process is a complex physical and chemical process, which is significant for the reliability and safety of the whole concrete structure. The properties of cement-based materials, such as concrete or mortar, at early age, are crucial for construction quality control and practical application. The continuous monitoring of the early age hydration, including initial and final setting times, is hereby of considerable importance. Compared with classical techniques such as penetration text, thermal analysis, x-ray diffraction (XRD), infrared radiation text (IR) and scanning electron microscopy [1] , recently continuous and non-destructive advanced methods to monitor the hydration process have been developed.

Various sound wave technique is used in civil engineering fields. The researchers, employ pulse-echo methods, wave reflection methods, resonant frequency methods, microwave adsorption methods, and so on. For instance, Pessiki and Carino used the impact-echo method to compare the measured wave velocity with the measured penetration resistance. They defined the setting of concrete as when wave velocity begins to increase or when a specified wave velocity is reached [2]. Chotard et al and Smith et al used longitudinal ultrasonic pulse velocity (UPV) method and found that the longitudinal ultrasonic pulse velocity is sensitive to the massive formation of hydrates and that the duration of its sharp increase corresponds to the cement stiffening process [1, 3]. Sayers and Grenfell compared the longitudinal and shear wave velocities with Biot theory, studying the acoustic response in cement suspensions and porous elastic

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cement paste, respectively [4]. The work of Sayers and Grenfell was extended to mortar and concrete by Nicolas Robeyst et al [5]. Van Den Abeele et al employed acoustic emission (AE) technique with linear and nonlinear ultrasonic/elastic wave spectroscopy to monitor the microstructural changes occurring in freshly poured concrete during curing [6].

Research on ultrasonic monitoring for setting has mainly focused on the change of wave velocity. Because the relation between the setting and the velocity is less clear, the point of setting cannot be determined unambiguously [2-6]. So some special analysis methods must be developed to gain detailed information of setting at early age hydration process.

Some researches, as previous publication, used embedded piezoelectric rods as the ultrasonic transducers. The embedded piezo-rod can generate ultrasonic waves propagating in the samples, and the wave could be received by other receiver piezoelectric rod. The transducers were embedded into cement based material and the properties of cement based material could affect the behavior of the transducer. Thus the monitoring by embedded transducers could obtain more information than normal ultrasonic monitoring [7, 8].

This study utilized the embedded piezoelectric transducers to monitor the hydration process of fresh concrete. The amplitude of the received waves propagating through the samples which is important parameter in ultrasonic non-destructive test, was analyzed on the hydration. Compared with penetration test result, it was found that the fluctuation of the amplitude development could effectively and reliably determine both the initial and final setting point.

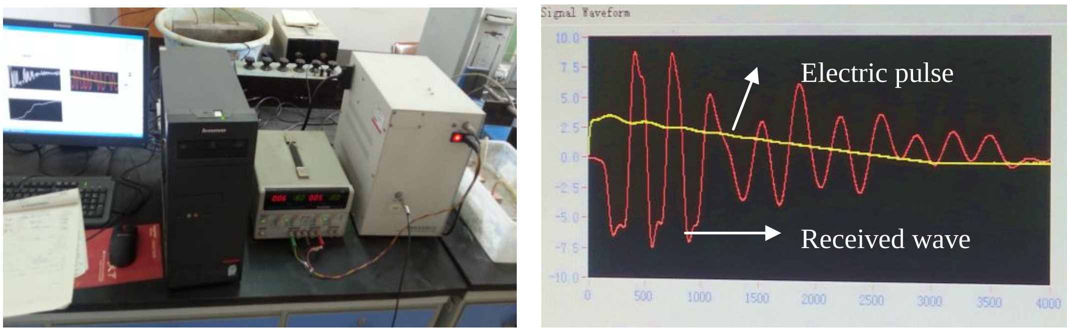
2. INSTRUMENT

2.1 Fabrication of transducers

The piezoelectric transducers were fabricated including the following steps: welding coaxial cable wires to the positive and negative electrodes of piezoelectric rods, coating the epoxy resin for insulation, coating the conductive layer as a shielding layer, and grounding. In brief, the coaxial cable was welded to the corresponding electrodes of the piezo-rod, with a thin layer of epoxy to insulate the path and coaxial cable. However, the receiving type should be enveloped of highly conductive materials, in this experiment silver paint was used as the shielding layer, which should be carefully coated. And then the mixture of epoxy resin and hardener was used as packaging material for the transducers. The piezoelectric transducer was of 4×4×4cm. The detailed fabricating process of the composites has been described in related reference [9].

2.2 Ultrasonic wave amplitude measurement

The ultrasonic measurement apparatus was employed for the continuous monitoring, as shown in Fig.1 (a). The paste with water/cement ratios of 0.5 and 0.6 was mixed thoroughly for 5 min, and then was poured into the container. The specimen was vibrated to remove the trapped air bubbles. After casting the fresh concrete in the plastic box, measurement of ultrasonic wave started immediately and continued for approximately 24h. The electric pulse of 300v was generated by ultrasonic device automatically every 6 min, because these intervals turn out to be sufficient to capture important details of the ultrasonic development. The input electric pulse and received wave were also shown in Fig.1(b). More details about the ultrasonic wave measurement and data acquisition were described in previous publication [7-10].



(a) (b)

Fig. 1 Ultrasonic monitor tests and the control interface

2.3 Penetration resistance text

Along with ultrasonic tests, the setting behavior was also monitored traditionally with the penetration resistance method (GB/T50080-2002) [11] on the mortar sieved from the fresh concrete mixtures as shown in Fig. 2. The time should be recorded at the beginning of mixing. The mortar sample was obtained by wet-sieving the fresh concrete through a 5-mm sieve[3] and poured into the containers.

Insert a needle of appropriate size, depending on the degree of setting of the fresh mortar, in this apparatus and bring the bearing surface of the needle into contact with the mortar surface. Gradually and uniformly apply a vertical force downward on the apparatus until the need penetrates the mortar to a depth of 25-mm. At regular time intervals, the force and the time of application was recorded, and calculated the penetration resistance using the formula

$$P = \frac{F}{S} \tag{1}$$

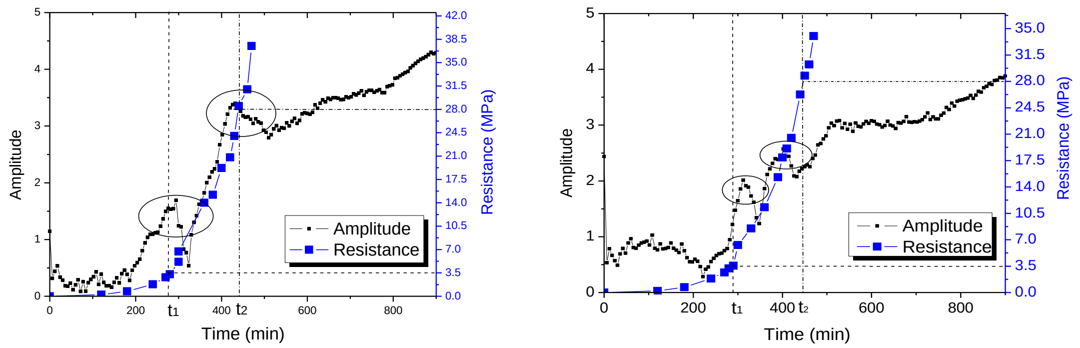
Where P = penetration resistance; F = the recorded force dividing the origin date; S= the bearing area of the needle. Continue testing until one at least penetration resistance reading equals or exceeds 28 MPa. From a plot of penetration resistance versus elapsed time, the times of initial and final setting are determined.

Fig. 2 Penetration resistance test

3. RESULTS and DISCUSSION

Fig. 3 (the blue line in a, b) shows the initial setting time (IST) and final setting time (FST). The setting time is determined when the penetration resistance equals 3.5 MPa and 28 MPa, respectively [12].

In this figure, it can also be noted that the penetration resistance curves of different w/c ratios developed similarly and the two critical points correspond to the initial and final setting times are approximately uniformity. Before the first setting point, the penetration resistance increases very slowly, due to the formation of hydration products. After that, a dramatic development of the hydration process appears when more and more hydration grains become connected and the state changes into water-saturated porous solid according to Boumiz et al [13].



(a) water/cement ratio of 0.5 (b) water/cement ratio of 0.6

Fig. 3 The penetration resistance and ultrasonic monitor time relationship curve

Fig. 3 (the black line in a, b) shows the ultrasonic amplitude monitoring. From the fresh stage to the hardened stage, obviously two inflection points appear, which are not observed in the previous publication.

To achieve the objective of this study, the evolution of amplitude was compared with the evolution of the penetration text for each concrete mixture. According to GB/T50080-2002, the IST and FST are 4.7 h and 7.3 h. In Fig. 3, the two inflection points on amplitude curve correspond very well with t_1 and t_2. The two inflection points can be considered as the indication of setting points of concrete. The ultrasonic method is appropriate for determining the setting time in real application. In previous ultrasonic research, which used surface bonded transducers, could not determine the setting accurately, because the transducers were embedded into the concrete. The properties of concrete would affect the behavior of the transducer and the setting point could be determined.

In order to characterize the evolution of amplitude curve during the setting and hardening process, four stages may be clearly identified on basis of the typical curve as shown in Fig. 4: In the first stage, after the short dissolution and dormant embargoing, the curve increases rapidly. In stage 2, it appears two special inflection points. In stage 3, it has a temporary flat, and then increases until reach a critical quantity with the stiffness raising. In the last stage, with high hydration degree the curve gradually levels off and approaches its asymptotic value.

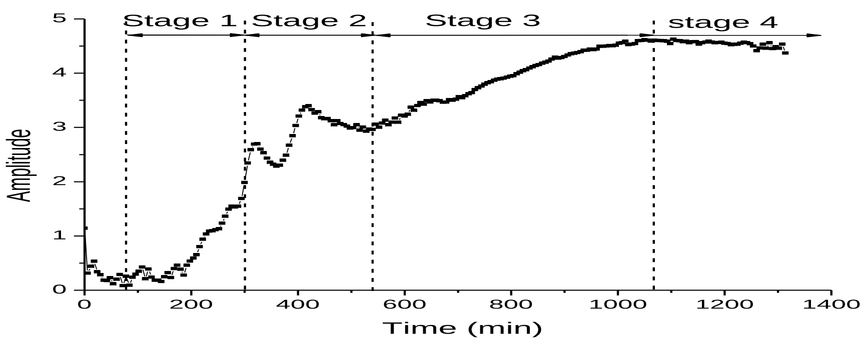


Fig. 4 The four stages of the hydration process

4. CONCLUSIONS

In this research, transducers were embedded into fresh concrete samples to generate and receive ultrasonic signals. The embedded transducers were employed to monitor the hydration process of fresh concrete paste. The penetration resistance method and ultrasonic monitor were analyzed and compared simultaneously. Conclusions can be drawn as followings:

(1) The ultrasonic monitor method can effectively determine the setting time of hydration process. This method by the amplitude analysis shows great practical prospect to the conventional method.

(2) It is feasible to use the technique to distinguish the hydration stage at early age, especially in the initial 24h.

(3) Many works still need to be furthered on the ultrasonic method in the future, especially the working mechanism of the transducer in the concrete.

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