***The Open Civil Engineering Journal,* 2014, *8*, 201-204**

Corrosion Monitoring Using Embedded Piezoelectric Sensors

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Abstract: In this research, a new type of corrosion monitoring technique for reinforce concrete was developed. The technique used piezoelectric sensors to detect the ultrasonic signals during corrosion. The mechanism of the method was presented. Experiment was carried out to monitor the corrosion process using piezoelectric sensors. The corrosion was also monitored using stain gauge for comparison.

Keywords: Concrete, corrosion, piezoelectric sensor, steel bar, ultrasonic.

INTRODUCTION

Reinforced concrete structure is widely used in modern construction. However, reinforced concrete tends to suffer from serious environmental conditions and the durability is a severe problem. One of the main causes of durability in reinforced concrete structures is reinforcement corrosion. Therefore, the maintenance of structures for their safety requires effective monitoring techniques for assessing the reinforcement corrosion. researchers have developed a variety of relatively mature methods of nondestructive testing, such as acoustic emission, electrochemical techniques and so on [1-10].

Recently, health monitoring based on modern smart materials have been developed very quickly. Piezoelectric material is one type of smart material and used very widely [11-15]. The material could be used as sensors and actuators. In this research, a new type of sensor was developed to monitor the corrosion of steel bar. The sensor used piezoelectric material to generate and receive ultrasonic waves. The waves were guided by the steel bar and the corrosion of the steel bar could be detected.

FABRECATION OF THE SENSOR

The piezoelectric sensor included two piezoelectric ceramic elements which were used for generating and receiving ultrasonic waves and one steel bar was used as wave guider. The diameter of the piezoelectric ceramic element was 10 mm and the thick was 1 mm. Coaxial cable was connected to the opposite electrodes of the piezoelectric ceramic element. Then, the piezoelectric ceramic was enclosed using epoxy. At last, the piezoelectric element was bonded onto the opposite surfaces of a steel bar of 100 mm. The sensor is shown in Fig. (**1**).

(**a**) Piezoelectric element

(**b**) Corrosion sensor

Fig. (1). Piezoelectric ceramic and the corrosion sensor.

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1874-1495/14 2014 Bentham Open

THE MECHANISM OF THE CORROSION DETECTION METHOD

As is known that the corrosion process is the accumulation of different types of oxidation products. The corroded part of a steel bar may induce increase of the volume because the corrosion products have different material properties. The steel bar was designed to guide the ultrasonic wave. When the sensor was embedded into concrete, part of the wave energy would transmit to the concrete. When the corrosion products were accumulated, less wave energy would emit to the concrete. Thus, during corrosion the wave amplitude would change. The working principle is shown in Fig. (**2**).

Before the corrosion sensor was embedded in concrete, the properties of the sensor were examined. One piezoelectric element was stimulated by an electric pulse from a signal generator (Agilent 33120A) and the other piezoelectric element was used to receive the ultrasonic wave, which was recorded by an oscilloscope (Tektronix TPS2024). The input electric pulse was a step function of ±10V. The input electric pulse and the received wave are shown in Fig. (**3**). The sensor was then cast into a concrete beam with a cover thickness of 10 mm. After one week curing, the operation was repeated. The received wave is shown in Fig. (**4**). After the sensor was embedded into concrete the wave amplitude decreased obviously. It could be seen that the sensor could response to the change of its surrounding state. Next, the sensor would be used to monitor the corrosion process.

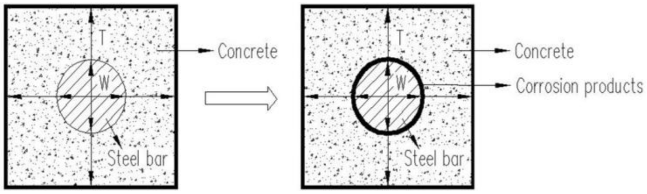


Fig. (2). Ultrasonic waves propagating in steel bar and concrete.

(W: wave propagating in steel bar; T: wave transmitted into concrete)

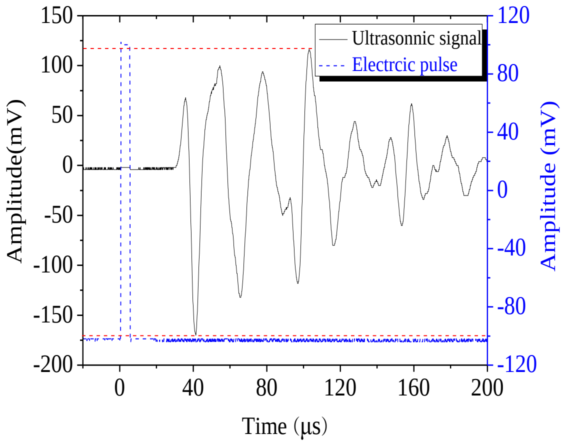


Fig. (3). Ultrasonic wave received before the sensor was embedded into concrete.

CORRISION ACCELERATION TEST

In order to accelerate corrosion process, the concrete specimen with embedded sensor was place in 3% NaCl solution and the corrosion circuit was connected using the direct-current power. The embedded reinforcement bar in the specimen was connected to the anode of the direct-current power and the cooper rod was connected to the cathode of the direct-current power [16]. Both ends of steel bar were connected with signal generator and oscilloscope. Strain gauge was also bonded onto the surface of the concrete beam to measure the strain of the specimen. The instruments in the acceleration test are shown in Fig. (**5**). The potential used in the acceleration test was 2 volts. The ultrasonic wave signals were measured per hour. Measurement was stopped until the cracks appeared on the surface of concrete specimen.

The waves recorded at 10 h and 60 h are shown in Fig. (**6**). During corrosion the amplitude of the wave increased. The reason is interpreted in the above. The corrosion product layer decreased the transmitted wave energy. Thus, the amplitude increased.

The relation of time, wave amplitude and strain is shown in Fig. (**7**). During the early stage of the corrosion, the wave amplitude and the strain both increased linearly.

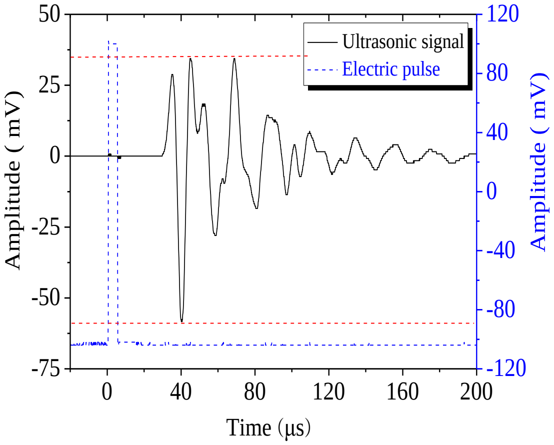


Fig. (4). Ultrasonic wave received after the sensor was embedded into concrete.

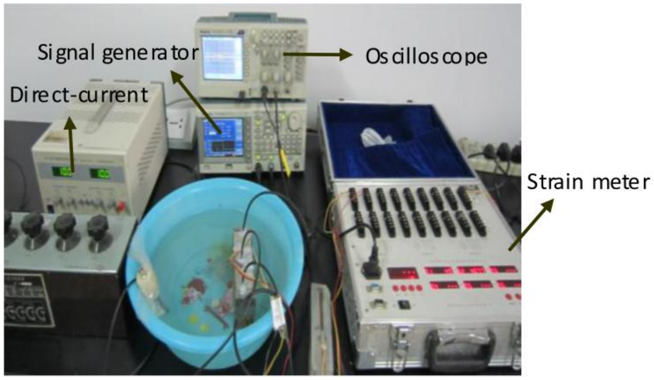
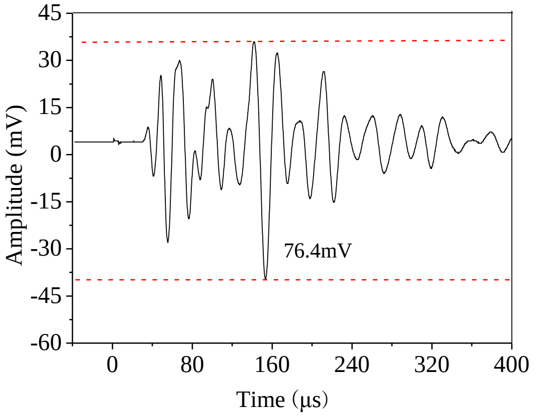
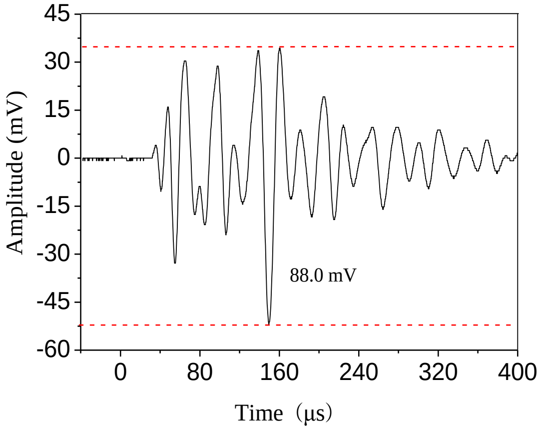


Fig. (5). Test instruments used in corrosion monitoring.



(**a**) Wave received at 10 h



(**b**) Wave received at 60 h

Fig. (6). Ultrasonic wave received in the test.

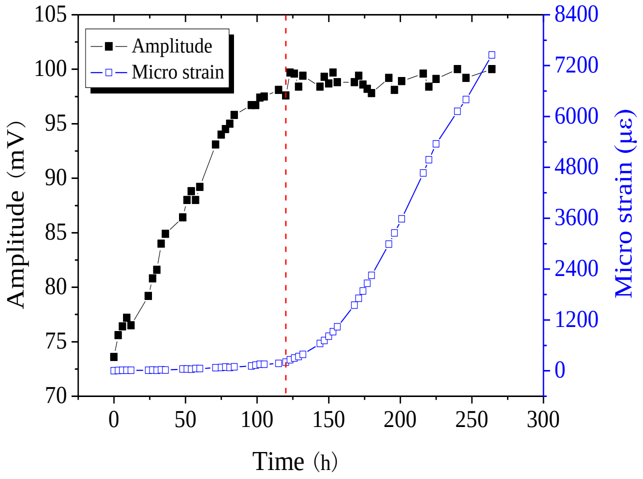


Fig. (7). Increase of amplitude and micro strain *versus* time.

At about 120 h, the amplitude stopped increasing and the strain increasing rate became very large. We know that when the strain increased very quickly, it means that small cracks around the steel bar were induced due to the expansion the corrosion product. The cracks changed the way the wave propagation from steel bar to concrete.

Thus, the amplitude of the wave could detect the initiation of the corrosion and the cracking of the concrete. It should be noted that the experiments had very good repeatability.

CONCLUSION

In this paper, a new type of piezoelectric sensor is applied to corrosion monitoring. The novel piezoelectric sensor include two piezoelectric ceramic elements which are used for generating and receiving ultrasonic waves and one steel bar was used as wave guider. The accumulation of the corrosion products changed the wave transmission. Thus, the wave amplitude increased with the corrosion process. It is very important that the method could detect the cracking of the concrete around the steel bar.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

ACKNOWLEDGEMENTS

The financial support is from the National Natural Science Foundation of China (51378239) and National Key Basic Research Program by MOST (Project No.271 2011CB013600; Issue No: 2011CB013604).

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Received: February 22, 2014 Revised: March 19, 2014 Accepted: March 21, 2014