Monitoring corrosion of steel bar using ultrasonic guided wave

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Abstract: The reinforcement corrosion was monitored using ultrasonic guided wave. The amplitude of ultrasonic guided wave could response the degree of reinforcement corrosion. The experiment was carried out to monitor the corrosion process. And the results indicated that ultrasonic guided wave could monitor reinforcement corrosion in reinforced concrete structure real-timely and online. It could reflect the degree of reinforcement corrosion effectively.

1. Introduction

Reinforced concrete (RC) is widely used in the civil engineering all over the world, because it has many advantages, such as low cost , high strength et al. However, rebar corrosion has occurred and it is currently one of the primary durability concerns for reinforced concrete structures[1]. Thus, it is necessary to monitor corrosion of reinforcing steel. There are many methods to monitor corrosion, such as acoustic emission[2], resistance probe[3] and Anode-Ladder method[4−6], Ultrasonic guided wave[7−9]. Ultrasonic guided wave has many advantages compared with traditional detection methods. Firstly, it can propagate a long distance. Secondly, it has high sensitivity. Thirdly, it has broad coverage. Moreover, Piezoelectric material was used as sensors and actuators in this paper. It was a kind of smart materials. The sensor was used to generate and receive ultrasonic waves. The waves were guided by the steel bar and the corrosion of the steel bar could be detected. This paper mainly confirmed the degree of reinforcement corrosion by the amplitude curves of ultrasonic guided wave.

2.The fabrication of piezoelectric ceramic sensor

There are many different types of piezoelectric materials, and the mostly used in civil engineering fields is piezoelectric transducer (PZT) ceramic. Thus, PZT ceramic was also adopted in this study as sensing element. The piezoelectric sensor included two piezoelectric ceramic elements which were used for generating and receiving ultrasonic waves.

The PZT ceramic peace with the thickness of 1.0 mm and the diameter of 10 mm was chosen. The coaxial wires were welded to the positive and negative electrode of piezoelectric ceramic piece, respectively. In order to block out noise, the shielding wire was soldered to the surface of the receiving piezoelectric sensor. What's more, silver should be painted in the surface of receiving piezoelectric sensor. The piezoelectric sensor was be wrapped by mixed materials, its proportion of cement powder, epoxy resin and curing agent is 1:1:0.25 by weight. The transducers were attached at the two ends of the bars by using glue. The sensor is shown in Fig. 1:

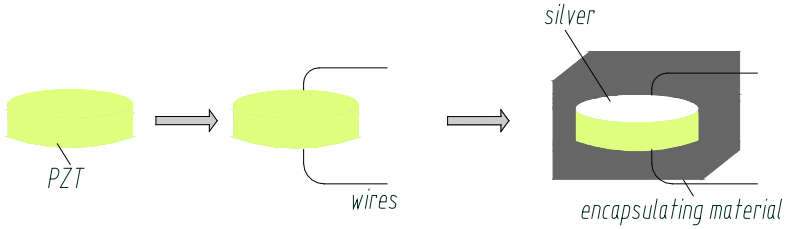

Fig. 1 The fabrication of piezoelectric sensor

3.The process of experiment

The experiment used the mortar with proportions of cement, sand and water as 1:2:0.55, because concrete was not used in this study to avoid possible interaction with large aggregates. The dimensions of the specimens is $150\text{mm} \times 150\text{mm} \times 40\text{mm}$, 10mm diameter plain mild steel bar of 13cm length was embedded in the center of the specimen at the time of casting.

In order to accelerate corrosion of rebar, the specimen was submerged in the salt water (5% NaCl). 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[10].

Both ends of steel bar were connected with signal generator and oscilloscope. After applying an electric current, The signal generator (Agilent 33120A) could be used to output continuous sine wave towards generating piezoelectric sensor. And the receiving piezoelectric sensor was used to receive the ultrasonic wave, which was recorded by an oscilloscope (TektronixTPS2024). The data is recorded every 3 hours until the cracks appeared on the surface of concrete specimen.. The experiment equipment was showed in Fig. 2.1 and Fig. 2.2:

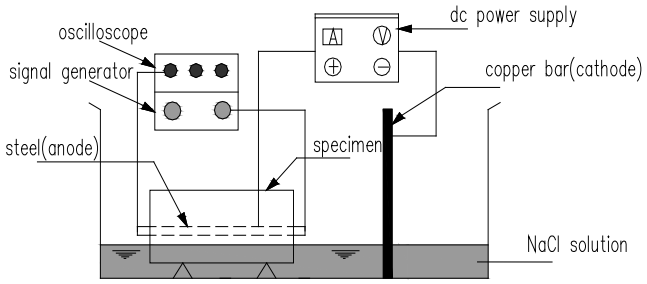

Fig. 2.1 the diagram of ultrasonic guided wave monitoring system

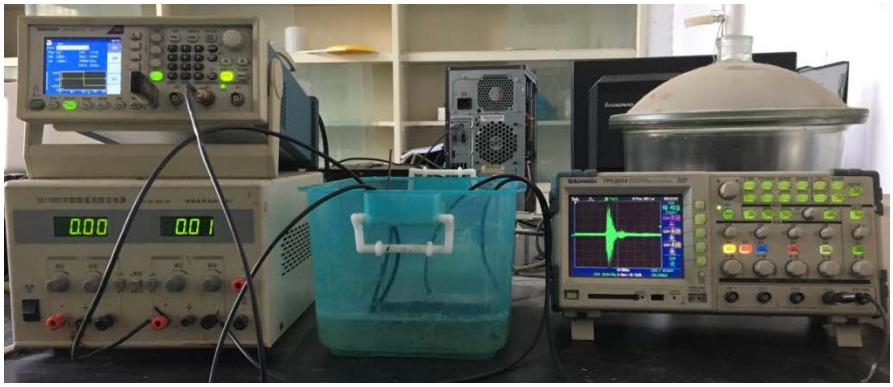

Fig. 2.2 the experimental diagram of ultrasonic guided wave

4.The result

The trend of the amplitude of the recorded signals can be seen in Fig. 3. The degree of the corrosion could be determined by the variety of the amplidtude.

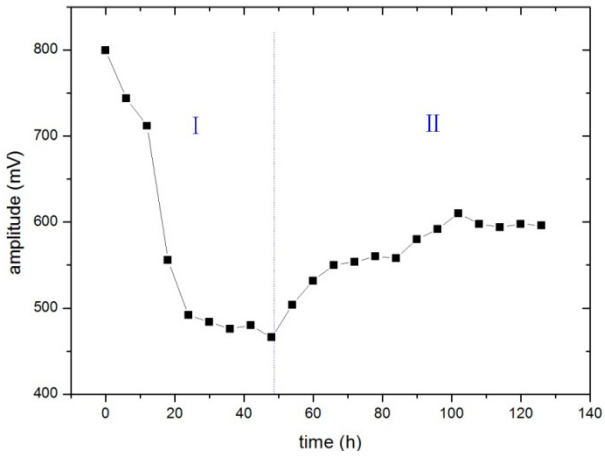

Fig. 3 the trend of the amplitude of ultrasonic guided wave

In the process of rebar corrosion , The trend of amplitude can be divided into two stages : drop and rise, respectively. The drop of amplitude responds to the first stage of rebar corrosion. With the accumulation of corrosion production, the rebar and mortar has good cohesion. So the energy of ultrasonic guided wave leaked into the surrounding mortar, which leaded to energy attenuation. With the increase of the degree of corrosion , wave which leaked into the surrounding mortar got more .

When the amplitude of corrosion got the lowest point, the crack started to occur.

The rising stage corresponds to the second stage mentioned above. At this time, cracks started to occur in the mortar. The interface of steel bar and concrete emerged to debond , which reduced the coupling of reinforced mortar and corrosion production. Obvious cracks began to occur and caused substantial bond damage, the amplitude has obvious rising trend.

Therefore, there is a corresponding relationship of the ultrasonic guided wave signal amplitude and corrosion time. Amplitude parameter is sensitive to the process of rebar corrosion,The difference of the steel bar corrosion stage can be reflected though the change tendency of amplitude.

5.Conclusions

In this paper, piezoelectric material was used as sensors and actuators. The experiment was carried out to monitor the corrosion process using ultrasonic guided wave. The amplitude of ultrasonic guided wave could response the degree of reinforcement corrosion in steel concrete structure real-timely and online. It could reflect the degree of reinforcement corrosion effectively.

6.Acknowledgements

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7.References

[1] Al-Sulaimani G J, Kaleemullah M, Busanbul I A, Rasheeduzzafar. Influence of corrosion and cracking on bond behavior and strength of reinforced concrete members[J]. ACI Structural Journal,1990, 87(2) :220–231.

[2] H. Mazille, R. Rothea, C. Tronel. An acoustic emission technique for monitoring pitting corrosion of austenitic stainless steels[J]. Corrosion Science, 1995,37(9):1365-1375.

[3] F.W. Mauldin Jr, F. Viola, W.F. Walker. Reduction of echo decorrelation via complex principal component filtering[J]. Ultrasound Medicine And Biology, 2009,35 (8) :1325–1343.

[4] Feliu S, Agonazlez J, Candrade M. Polarization Resisitace measurements in large concrete speciments:mathematical solution for a unidirectional current distribution[J]. Material and Structure, 1989,22(3): 199-205.

[5] Feliu S, Agonazlez J, Candrade M. Determining Polarization Resistance in Reinforced Concrete Slabs[J]. Corrosion Science,1989, 29(1): 47-52.

[6] Feliu S, Agonazlez J, Candrade M. Confinemengt of the Electrical Signal for in sige Measurement of Polarization Resistance in Reinforced Concerte[J]. ACI Material Journal V. 87, No. 5, 1990.

[7] WB Na, T Kundu, MR Ehsani. Ultrasonic guided waves for steel bar concrete interface testing[J]. Materials Evaluation,2002,60(3):437-444.

[8] Miller T,Yanagita T,Kundu T. Nondestructive inspection of reinforced concrete structures[C]. Health Monitoring of Structural and Biological Systems, Proceedings of SPIE ,2009,9725:7295 OM 1-12.

[9] Beard M D 2002 Guided wave inspection of embedded cylindrical structures PhD Thesis University of London.

[10] B. H. Oh, K. H. Kim and B. S. Jang. Critical corrosion amount to cause cracking of reinforced concrete structures. Acid Mat.J,vol.7, pp.333-339, 2009.