Monitoring steel corrosion by using the combination of ultrasonic guided wave and acoustic emission

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Abstract. Corrosion of steel bars in reinforced concrete structure will reduce the bearing capacity of the structure, which will cause damage to the structure and cause great casualties and economic losses. In this paper, the same specimen was monitored by using the ultrasonic guided wave (UGW) and acoustic emission (AE). The variation trend of the cumulative number of acoustic emission impacts and the amplitude variation trend of ultrasonic guided waves were obtained in the process of monitoring steel corrosion. By analysing the curve of cumulative number of impacts and the curve of the amplitude of ultrasonic guided wave changing with time, it can be accurately obtained that the corrosion of steel reinforcement can be divided into three stages, so that the feasibility of monitoring the corrosion process of steel reinforcement can be verified by ultrasonic guided wave and acoustic emission.

1. Introduction

The combined use of steel and concrete has created great social effect, and the problem of reduced durability of concrete structure caused by steel corrosion has become more and more serious.[1,2] Nondestructive testing (NDT) plays an important role in the defect monitoring of building structures because of its advantages.[3,4] Ultrasonic guided wave technology is an active monitoring technology, which requires the signal generator to generate excitation signal for the transmitting sensor, and the signal is received by the receiving sensor and transmitted to the oscilloscope. It has the characteristics of real-time, high sensitivity and on-line monitoring. [5,7] The curve of amplitude over time can be obtained by using UGW. Acoustic emission technology is a passive monitoring technology, that is, no external input energy is needed to monitor the defects. It has the characteristics of real-time, dynamic and online monitoring. [8,10] In the process of monitoring steel corrosion, the change curve of cumulative impact number with time can be obtained. In this paper, two kinds of NDT techniques are combined to monitor the same specimen which was accelerated corrosion by electrochemical methods, and the corrosion process of steel reinforcement is analyzed by comparing the two curves.

2. The principle of ultrasonic guided wave and acoustic emission monitoring technology

Acoustic emission technology refers to the physical phenomenon that local acoustic emission sources release energy rapidly and generate transient elastic waves under the action of internal force or external force. Acoustic emission can reflect some characteristics of the material in the process of failure. Since the signal comes from the material itself, the acoustic emission sensor attached to the external surface
or embedded in the material can receive the signal directly. Therefore, acoustic emission detection can
detect local defects without scanning the whole structure. When the structure is damaged, the AE sensor
will receive some signals from the AE source and transmit them to the AE system through the
preamplifier. And then, the acoustic emission waveform signal and parameter signal are analyzed to
obtain the information of acoustic emission source. The figure 1 shows the acoustic emission source of
steel corrosion in concrete.

![Figure 1: Acoustic emission sources in concrete](image1.png)

The basic principle of ultrasonic guided wave monitoring technology is that piezoelectric ceramic
transmitting sensor and receiving sensor are pasted on the surface of the structure or embedded inside
the structure to transmit and receive waveform signals. According to wave theory, diffraction, reflection
and transmission will occur when guided waves encounter cracks or obstacles in the propagation process
of reinforced concrete structures. The occurrence process of steel corrosion is ensured by studying the
ultrasonic guided wave changes. The basic components of the ultrasonic guided wave monitoring system
are shown in the figure 2.

![Figure 2: The monitoring system of ultrasonic guided wave](image2.png)

3. Experimental process

3.1. Specimen details
The size of test block is 100mm×100mm×400mm. A single steel bar of diameter 10mm and 400mm
length was embedded at the centre of specimen. In order to conduct ultrasonic and acoustic emission
monitoring on the specimen at the same time, it is necessary to affix sensors on both ends of the steel
bar. In addition, a wire is welded in the middle of the steel bar, and the test block is poured by using the
standard concrete test block production process. After the test block is made, both ends of the test block
are encapsulated to prevent the chloride ion from invading and damaging the piezoelectric element.
during the electrochemical accelerated corrosion. And then, the test blocks are put into the standard curing room for curing, and the prepared test blocks are shown in the figure 3.

![Figure 3 Steel bar and specimen](image)

**Figure 3** Steel bar and specimen

### 3.2. The process of accelerated corrosion

In the natural state, the rate of steel corrosion is very slow. Therefore, the method of external dc power supply is applied for accelerated corrosion in this experiment. The specimens were soaked in 5% NaCl solution. The positive pole of the dc power supply was connected with the steel reinforcement, and the copper rod was connected with the negative pole of the DC power supply. The voltage of the DC power supply in the accelerated corrosion test is 2V, and the corrosion current is maintained at 0.01A by controlling the applied resistance. Accelerated corrosion diagram of external DC power supply is shown in the figure 4.

![Figure 4 Acoustic emission and ultrasonic monitoring system under accelerated corrosion](image)

**Figure 4** Acoustic emission and ultrasonic monitoring system under accelerated corrosion

### 3.3. Monitoring the reinforcement corrosion

The PCI-2 acoustic emission instrument produced by American physical acoustics (PAC) was used in the acoustic emission monitoring process. The ultrasonic monitoring process adopts the signal generator produced by Tektronix and DSO-X 2024A oscilloscope produced by agilent. As shown in the figure 5.
The curve of cumulative impact number change and the curve of amplitude change over time are shown in figure 6. It can be seen that the process of corrosion can be divided into three stages.

As can be seen from the above diagram, in the early stages of the reinforcement corrosion (i.e., the first stage of the reinforcement corrosion), the amplitude of ultrasonic guided wave tends to decrease and the cumulative number of AE impact is small. The reason for this phenomenon is that in this stage, with the accumulation of corrosion products of steel reinforcement, the coupling degree between steel reinforcement and concrete increases. The energy of ultrasonic guided wave leaks into the concrete, so the amplitude decreases with time. In addition, the internal damage of concrete is small, and the signal of acoustic emission is less.

With the increase of corrosion time, the test block enters the second stage of corrosion, and micro-cracks appear in concrete. At this stage, the amplitude of ultrasonic guided wave continues to rise, and the cumulative number of impacts increases. Due to the expansion of crack in concrete, the interface between steel and concrete is debonded that caused the increasing of amplitude. The micro-cracks in concrete develop rapidly which caused the formation of microfracture zones and the appearance of concrete cracking. The process of the formation of micro-fracture zones and the development of cracks will accumulate higher energy and energy is released through acoustic emission. Therefore, this stage corresponds to the rapid development of micro-cracks in the concrete, and the ae count shows a characteristic of growth.

As the reinforcement enters the third stage of corrosion, visible cracks appear on the concrete surface, the amplitude of ultrasonic guided wave tends to be gentle, and the cumulative number of acoustic emission impact curve continues to rise, and then tends to be gentle. After the macro crack appears in
the concrete specimen, the steel bar is completely separated from the concrete, and the guided wave only propagates along the steel bar itself, so the amplitude curve of ultrasonic guided wave tends to be stable. The change curve of the cumulative number of hits has sudden changes when the macroscopic cracks appear. The reason for this is that much energy is released. However, in the process of crack development, there are two aspects that will play a role in limiting the development of cracks: on the one hand, the mechanical properties of coarse aggregate and cement matrix in reinforced concrete; on the other hand, the internal reinforcement of concrete.

4. Conclusion
As a passive monitoring technology, acoustic emission technology can obtain the cumulative change curve of the number of impacts by recording the number of impacts which do not need to input external energy. While ultrasonic guided wave technology, as an active monitoring technology, can obtain the amplitude change curve with time by recording the amplitude at each moment. In this study, by comparing the curve of cumulative impact number change and the curve of amplitude change with time, it can be known that both acoustic emission technology and ultrasonic guided wave technology can quantify the corrosion process of steel reinforcement that is divided into three stages. When acoustic emission and ultrasonic technology are combined, they can be mutually verified to be feasible for monitoring the corrosion process of steel reinforcement. In addition, when they jointly monitor steel corrosion, they can better divide the steel corrosion stage and have an early warning effect on the steel corrosion process in the building structure.

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