17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

Development of reinforced concrete corrosion amount presumption method by ultrasonic method

Yousuke SAKURADA
NTT Access Network Service Systems Laboratories
1-7-1, Hanabatake, Tsukuba-shi, Ibaraki, 305-0805 Japan
Tel: +81 29 868 6231, Fax: +81 29 868 6259
E-mail: yousuke_sakurada@ansl.ntt.co.jp
Hiroshi IRIE
NTT Access Network Service Systems Laboratories
E-mail: h.irie@ansl.ntt.co.jp
Yasukatsu YOSHIDA
NTT Access Network Service Systems Laboratories
E-mail: y.yoshida@ansl.ntt.co.jp

Abstract

The aim of this study is to measure the level of reinforcing rod corrosion in concrete structures by means of fully non-destructive measurements.

In this report, a two transducer method (oscillator: diameter 20 mm, central frequency 2.0 MHz; sensor: diameter 20 mm, central frequency 2.0 MHz, and diameter 40 mm, central frequency 500 kHz) was used to apply ultrasonic to test pieces in which varying levels of reinforcing rod corrosion weight loss had been induced by electrolytic corrosion. As a result, the spectral intensity in the 100–300 kHz band was fond to be correlated to the amount of reinforcing rod corrosion when using a 20 mm diameter transducer on the receiving side when the reinforcement rod covering is 10 mm or 30 mm, and when using a 40 mm diameter transducer on the receiving side when the reinforcement rod covering is 50 mm.

Keywords: ultrasonic reflection technique, electrolytic corrosion, power spectrum, reinforcing rod corrosion, concrete structure

1. Introduction

In recent years, there have been a growing number of incidents where various factors have led to the degradation or failure of reinforced concrete (RC) structures that were designed to be semi-permanent.[1] RC structures are designed with reinforcing rods integrated with the concrete in order to prevent failure due to tensile or compressive forces, so it is essential that the concrete and reinforcing rods maintain their design strength. However, problems such as cracking of concrete and corrosion of reinforcing rods can cause this strength to be lost. In particular, the corrosion of reinforcing rods can lead to reduced strength resulting from cracking and flaking of the covering concrete and the reinforcing rods themselves as a result of swelling and compression caused by the formation of rust. Promptly and accurately ascertaining the state of corrosion is thus an essential factor in the implementation of suitable maintenance administration of RC structures.

In this study we used electrolytic corrosion to produce concrete test pieces with different levels of reinforcing rod corrosion, and we investigated the possibility of estimating the amount of reinforcing rod corrosion by using a two transducer method to apply ultrasonic to reinforcing rods in test pieces and measure the reflected waves. The test pieces were taken apart after the ultrasonic measurements, and we investigated the relationship between the rate of mass reduction caused by corrosion (referred to as the corrosion loss rate) and the intensity of the power spectrum of the reflected waves after bandpass filtering.

2. Experimental outline and experimental method

2.1 Test piece production and electrolytic corrosion

Figure 1 shows the basic structure of the test pieces used in these experiments, and Table 1 shows their composition. The test pieces consisted of reinforced concrete sections measuring 200 mm long × 300 mm wide × 200 mm thick, and used D16 reinforcing rods. The reinforcing rod covering surface was set to one surface of the test piece, and the reinforcing rod covering depths were set to 10, 30 and 50 mm. Also, the number of test pieces was set to $N = 3$. When producing the test pieces, cylindrical test pieces (100 mm diameter × 200 mm tall) were produced for compression strength testing. The compression strength was 28.8–31.5 N/mm^2 at an age of 7 days.

Fig. 1: Test piece configuration (dimensions in mm)

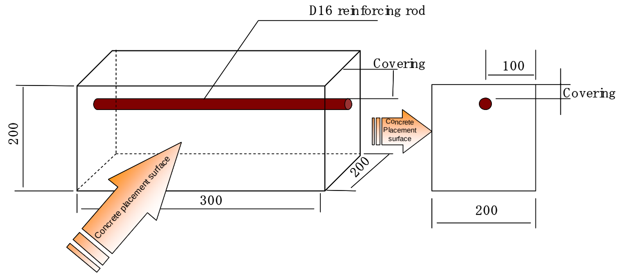


Table 1: Test piece composition

W/C (%)	Air (%)	s /a (%)	Bulk density (kg/m^3)					
			W	C	S	G	AE plasticizer	NaCl
60	4.5	51	163	272	940	913	C×0.25%	4.904

Fig. 2: Electrolytic corrosion set-up

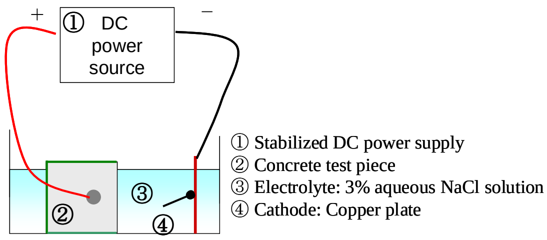


Photo 1: The appearance of cracking in a test piece with a corrosion loss rate of 3.01 wt%

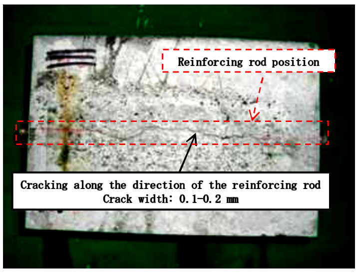
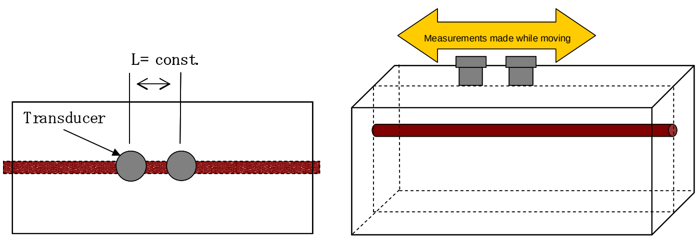


Fig. 3: Ultrasonic measurement method



To forcibly cause the reinforcing rods to become corroded, accelerated corrosion tests were performed using electrolytic corrosion. The electrolytic corrosion set-up is shown in Fig. 2. The corrosion circuit uses a 3% aqueous solution of NaCl as the electrolyte, the reinforcing rod (Fe) as the anode, and a copper plate (Cu) as the cathode. A fixed DC current of 100 mA is applied to the system. To facilitate the flow of current from the reinforcing rod covering surface, a coating of epoxy resin was applied to the other 5 surfaces.

The amount of corrosion was controlled based on the duration of the current flow. When this led to cracking in the reinforcing rod covering surface,[2] it is thought that the corrosion products leached out into the electrolyte, thereby reducing the corrosion expansion pressure. Therefore, the maximum duration of the electrolysis current was set to the time at which cracking occurred (Photo 1). Test pieces were also produced by allowing the current to flow for half as much time.

To measure the mass of the reinforcing rod corrosion inside the test pieces produced by electrolytic corrosion, we performed ultrasonic measurement tests and then we took the test pieces apart, extracted the reinforcing rods, soaked then in a 10% aqueous solution of diammonium citrate for 24–48 hours to remove the corrosion products, and then measured their mass.

From these mass values and the mass of the reinforcing rods before they were corroded, we calculated the corrosion loss rates. This calculation was done using formula (1) as shown below.

$$\text{(Corrosion loss rate)} = \frac{\text{(Mass of reinforcing rod after corrosion)}}{\text{(Mass of reinforcing rod before corrosion)}} \times 100 \quad \text{(wt\%)} \quad \Lambda(\ 1\ )$$

2.2 Ultrasonic measurements

Figure 3 shows how the ultrasonic measurements were made in these tests. We employed a two transducer measurement method, using ultrasonic transducers made by Japan Probe Co., Ltd. These measurements were made while moving the transducer along the direction of the reinforcing rod in order to capture waves reflected from the entire reinforcing rod. During these measurements, the transducer was separated from the test piece by a fixed gap. The transducer diameter was 20 mm on the emitting side (central frequency: 2.0 MHz) and 20 mm or 40 mm on the receiving side (central frequency: 500 kHz). We also used an UCM2000 ultrasonic pulser/receiver made by H&B.

3. Experimental results and analysis of reflected waves

3.1 Results of experiments using electrolytic corrosion to promote corrosion

Figure 4 shows the results of the corrosion promotion experiments. In these experiments, the corrosion loss rate of the corroded reinforcing rods was from 1.01 to 3.55 wt%. Comparing the results obtained with reinforcing rod covering depths of 10 mm and 50 mm, we observed a trend whereby longer application of the electrolysis current resulted in a larger corrosion loss rate. The corrosion loss rates were of a similar order. With a covering depth of 30 mm, the relationship between the electrolysis time and corrosion loss rate exhibited a similar trend to the other covering depths, but the corrosion loss rate was larger.

Photo 2 shows the appearance of a corroded reinforcing rod. At corrosion loss rates of approximately 1.5 wt% and above, the corrosion covered almost the entire surface of the reinforcing rod.

3.2 Power spectrum of reflected ultrasonic

Prior to these experiments, we conducted transmission method experiments to calculate the speed of sonic in the concrete and the time taken for the waves transmitted from the reinforcing rod covering to be reflected by the reinforcing rods. The results were subjected to Fourier transformation focusing on the reflected waves captured in the vicinity of this arrival time.

Figure 5 shows an example of a reflected power spectrum. The frequency range of the waves reflected from the reinforcing rod was from 0 to approximately 300 kHz, but in the frequency band from 0 to approximately 100 kHz, we observed no large differences in the spectral intensity at different corrosion loss rates. However, in the frequency band above 100 kHz, the spectral intensity was found to decrease as the corrosion loss rate increased.

Fig. 4: Results of accelerated corrosion experiments using electrolytic corrosion

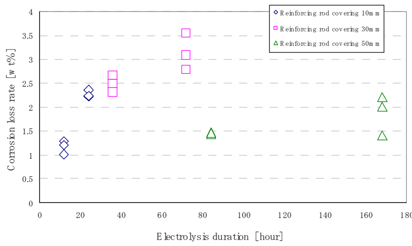


Photo 2: A reinforcing rod subjected to a corrosion rate of 3.01 wt%

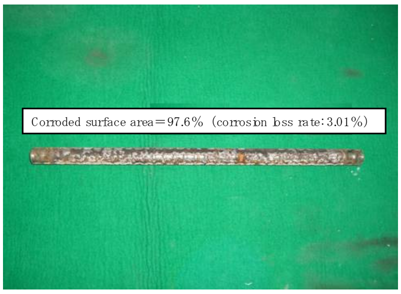
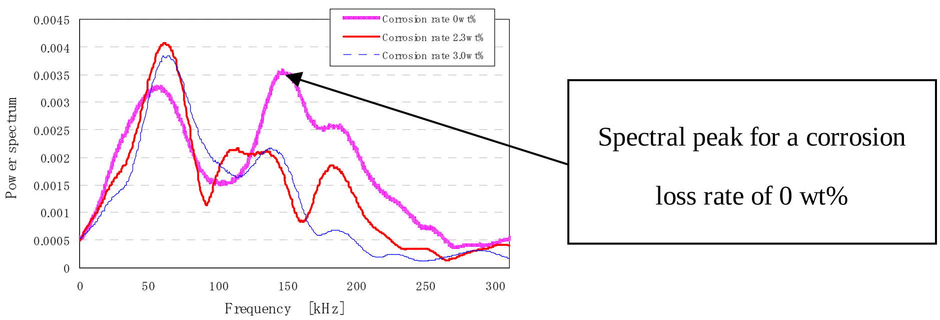


Fig. 5: Ultrasonic spectra reflected from reinforcing rods (reinforcing rod covering: 30 mm)



3.3 Correlation between power spectrum and corrosion loss rate

Next, we investigated the correlation between the spectral intensity (spectral area) and corrosion loss rate. The investigated frequency range was the 100–300 kHz band in which the differences in spectral intensity were observed, and when calculating the spectral area, we searched for the most effective filtering method by varying the bandwidth of the bandpass filter. As a result, we found two techniques for observing the correlation between the spectral area and corrosion loss rate, which are as follows:

(1) Bandpass filtering in the 200–300 kHz band

Figure 6 shows the relationship between the spectral area and corrosion loss rate when bandpass filtering is applied in the 200–300 kHz band. When the reinforcing rod covering depth is 10 mm, the correlation coefficient is $r = 0.79$ when the transducer diameter on the receiving side is 20 mm, but $r = 0.11$ when the transducer diameter on the receiving side is 40 mm. When the reinforcing rod covering depth is 30 mm, the correlation coefficient is $r = 0.92$ for a 20 mm transducer, and $r = 0.75$ for a 40 mm transducer. On the other hand, when the reinforcing rod covering depth is 50 mm, the correlation coefficient is r = 0.57 for a 20 mm transducer, and r = 0.90 for a 40 mm transducer, showing a different trend to that obtained with rod covering depths of 10 and 30 mm.

(2) Bandpass filtering in the frequency band from the spectral peak frequency at a corrosion loss rate of 0 wt% up to 300 kHz

Figure 7 shows the relationship between the spectral area and corrosion loss rate when bandpass filtering is applied in the band from the spectral peak at a corrosion weight loss of 0 wt% up to 300 kHz. The relationship between the transducer diameter on the receiving side and the reinforcing rod covering depth exhibits a similar trend to case (1) above. The correlation coefficients for reinforcing rod covering depths of 10, 30 and 50 mm were r = 0.84, 0.74 and 0.78 respectively, with slightly smaller values obtained for covering depths greater than 10 mm. Also, the sum total of the spectral area was about twice as large as in case (1).

Fig. 6: Spectral area in the 200–300 kHz band and corrosion loss rate

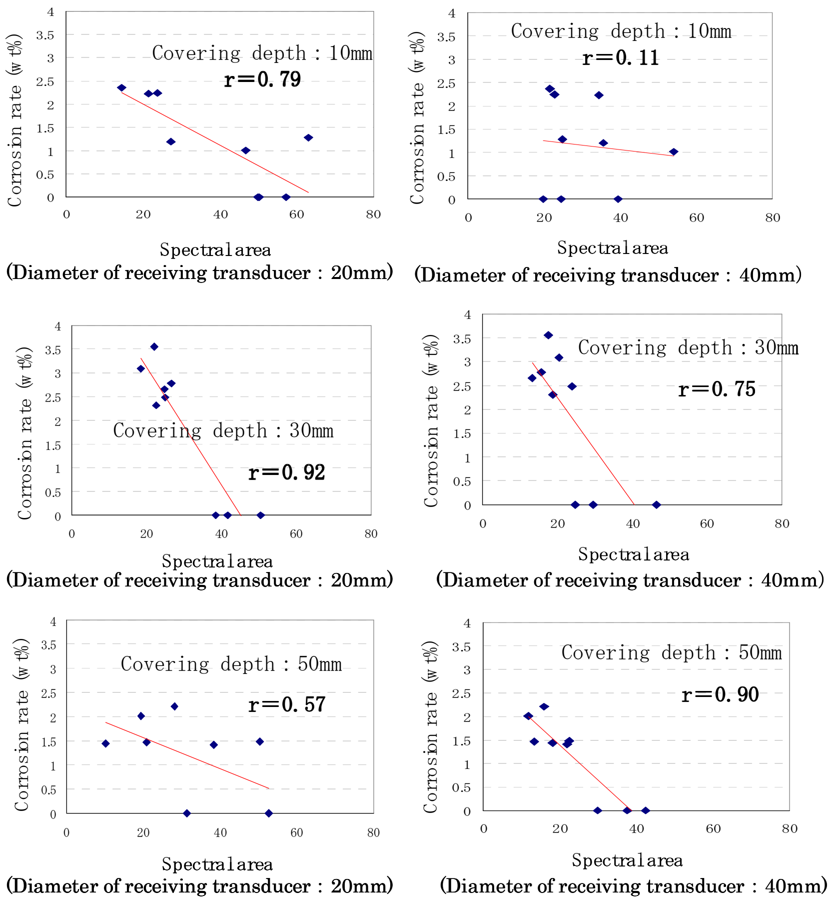
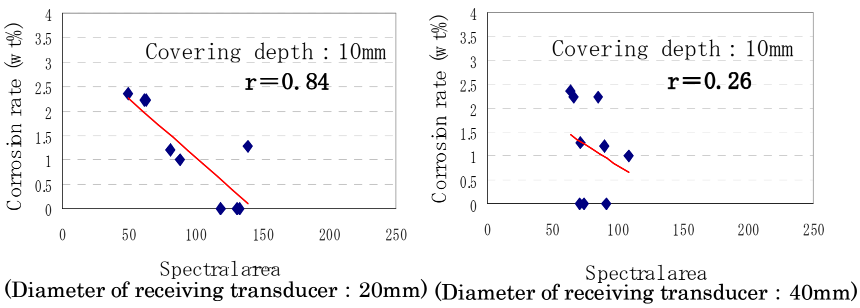
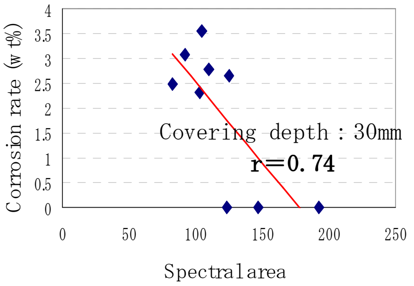
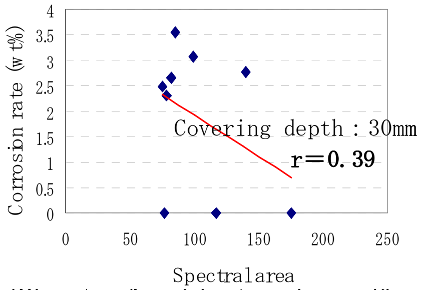


Fig. 7: Spectral area and corrosion loss rate in the band from the spectral peak at a corrosion weight loss of 0 wt% up to 300 kHz

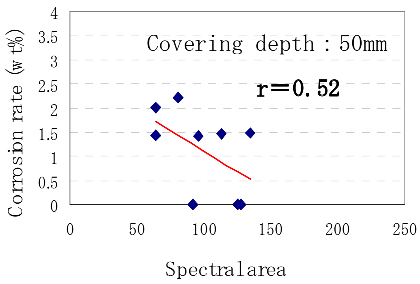




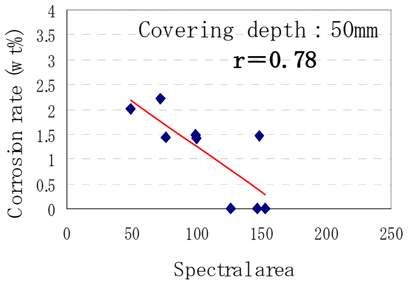
(Diameter of receiving transducer : 20mm)



(Diameter of receiving transducer : 40mm)



(Diameter of receiving transducer : 20mm)



(Diameter of receiving transducer : 40mm)

4. Discussion and future prospects

As a result of conducting these experiments, we have learnt the following:

(i) When the reinforcing rods in concrete test pieces with the same composition are corroded by electrolytic corrosion and subjected to non-destructive ultrasonic measurements, a correlation exists between the spectral intensity of the waves reflected from the reinforcing rods and their corrosion loss rates.

This is thought to be affected by the following factors which accompany corrosion of the reinforcing rods:

- Changes in the shape of the reinforcing rods
- The difference in density between the corrosion products and reinforcing rods
- The occurrence of cracking

In the future, we plan to survey and investigate which of the multiple possible factors dominate this phenomenon.

(ii) We have found that a receiving end transducer diameter of 20 mm is effective for reinforcing rod covering depths of 10 and 30 mm, while a receiving end transducer diameter of 40 mm is effective for a reinforcing rod covering depth of 50 mm. In the future, this relationship between the reinforcing rod covering depth and the receiving end transducer diameter should be clarified.

References

[1] JSCE Concrete Committee: “2001 Concrete Standard Specifications (Maintenance Edition)”

[2] Ishitobi et al.: “Study of corrosion expansion factors in test pieces used to model corrosion of reinforcing rods by electrolytic corrosion,” Annual Meeting of JSCE Kansai Division, 2006