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# Measurements of Acoustically Stimulated Electro-magnetic Response from Reinforcing Steel Bars
鉄筋からの音響誘起電磁応答の測定

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## 1. Introduction

Concrete has high resistance to compressive stresses, but it has relatively low resistance to tensile stresses. For this reason, reinforced concrete (RC) contains reinforcing bars (usually made of steel) to resist the tensile stresses. In the RC structures, however, the strength performance is significantly reduced when cracks spread to the surface of concrete by the corrosion and expansion of the reinforcing steel bars. Because main inspection is currently a visual check for infrastructures, the degradation is found after cracks occurred on the surface of concrete. This results in great expense for massive renovation and reinforcement. For cost reduction and the life extension of infrastructure, preventive maintenance through nondestructive evaluation is highly required.

Although the position of reinforcing steel bars can be measured by ultrasonic inspection or radar tomography,[1)] no direct inspection technique for the earlier-stage steel corrosion is established. In this work, we focus on the differences in the magnetic properties between corrosion products and host material (steel). Typical corrosion products are ferromagnetic black rust (magnetite, $Fe_3O_4$) and paramagnetic red rust ($Fe_2O_3$). In the earlier-stage corrosion, the thickness of rust is a few hundred micrometers. If such thin rust layers with different magnetic properties can be nondestructively identified, preventive maintenance will be realized.

Recently, a novel magnetic sensing method via ultrasonic excitation is demonstrated.[2-4)] In this method, nondestructive magnetic imaging and hysteresis measurements are demonstrated through the detection of acoustically stimulated electro-magnetic (ASEM) fields. In concrete inspection, it is necessary to irradiate the low-frequency ultrasonic wave (below 500 kHz). Although the wavelengths in concrete and steel are 6 mm and 10 mm, respectively, at 500 kHz, the occurrence region of EM fields induced by ultrasonic excitation will be limited to the skin depth of EM waves (about 10 μm) in steel bars. It follows that ASEM response is sensitive to a slight corrosion products formed on the surface of steel bars. The purpose of this work is to verify the detection of the corrosion products on the steel surface. In this experiment, we compared between a polished round steel and unpolished round steels with mill scale (black rust).

## 2. Experimental Setup

The specimens measured are different three steel bars (polished round steel (SGD3), round steel with mill scale (SR235), deformed round steel with mill scale (SD345)) as shown in Fig. 1(a). The thickness of mill scale is typically about 25 μm (Fig. 1(b)). The specimens are placed in a water tank at a distance (about 10 cm) from a 500 kHz transducer (Fig. 2). Static magnetic fields are applied by a home-made electromagnet. ASEM signals are detected by a loop antenna (coil) tuned at 500 kHz. The ASEM signals are amplified by a low noise preamplifier (46 dB) and echo signals are attenuated (-20 dB). The magnetic fields are applied to the direction of the long axis of the reinforcing bars.

(a)

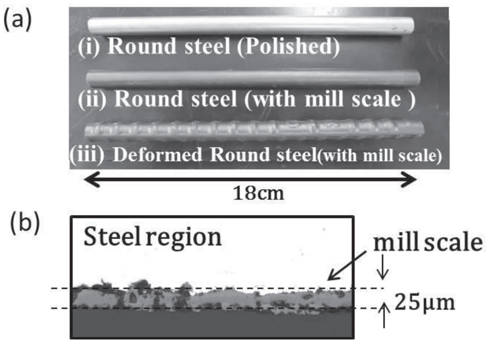


Fig. 1 Photograph of specimens. (a) Three different round steels. (b) Cross section of specimen (ii).

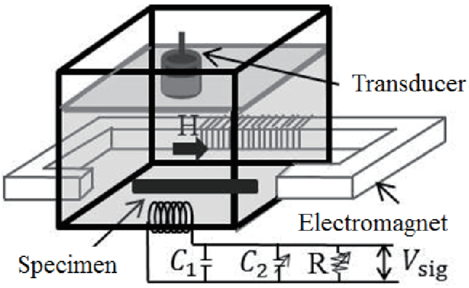


Fig. 2 Schematics of the measurement setup.

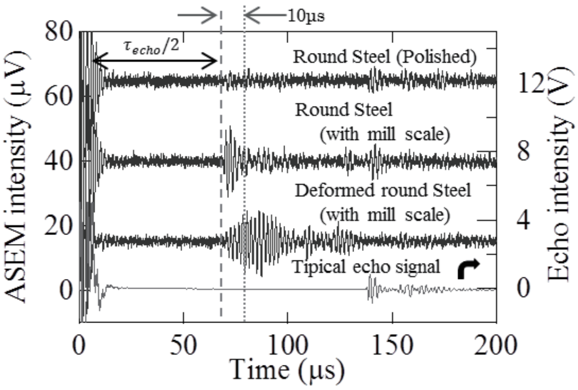


Fig. 3 Time traces of ASEM signals in three different round steels and a typical echo signal in round steel with mill scale. A current of 5 A, corresponding to a magnetic field larger than coercive force, is applied.

## 3. Results

Figure 3 shows ASEM signals and a typical echo signal in round steels. No significant difference in echo signal is observed between polished and unpolished round steels. The ASEM signals are identified at a half of echo delay time ( $\tau_{\mathrm{echo}}/2 \cong 70\,\mu\mathrm{s}$ ). The signal intensity in unpolished steels is clearly larger than that in polished steel bars, suggesting that ASEM response is highly sensitive to the presence of thin mill scale. Using typical values of the electric resistivity $\rho = 2 \times 10^{-7}\Omega\mathrm{m}$ and the relative permeability 2000 of steel, the skin depth of EM waves is estimated to be about $7\ \mu\mathrm{m}$. Thereby, the contribution of the host material (steel) will be small in ASEM response even for the low-frequency ultrasonic irradiation.

Figure 4 shows ASEM hysteresis loops of three different steel bars. The intensity is defined as the integration of absolute value of waveform in an interval between $\tau_{\mathrm{echo}}/2$ and $\tau_{\mathrm{echo}}/2 + \Delta t$, [4] where $\Delta t = 10\,\mu\mathrm{s}$ is taken in this experiment because of an antenna bandwidth of 100 kHz. The magnetic-field dependence of signal intensity is clearly observed in unpolished steels with mill scale (Fig. 4(b) and 4(c)). This strongly indicates that the ferromagnetic properties of mill scale are distinguished from that of the host material in ASEM response.

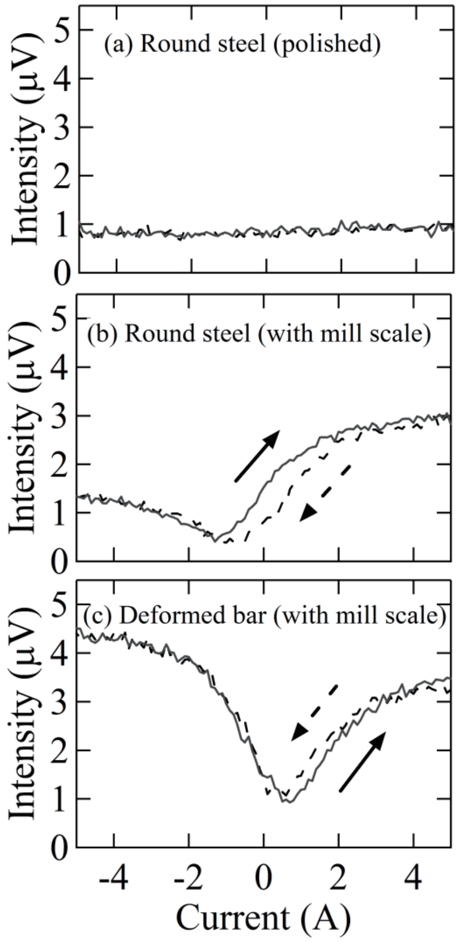


Fig. 4 ASEM hysteresis loops of three different steel bars. The solid and dashed curves show the upward and downward of magnetic fields, respectively.

## 4. Conclusion

The detection of 25 μm-thickness mill scale is verified even in the low-frequency ASEM method, suggesting a high potentiality of this method for steel corrosion inspection in RC structures.

## Acknowledgment

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