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Nondestructive inspection of austenitic stainless steels by detection of acoustically stimulated electromagnetic response

超音波誘起電磁応答の検出によるオーステナイト系ステンレス合金の非破壊検査

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1. Introduction

Ultrasonic techniques are widely used for nondestructive inspection. Ultrasonic has two important features. One is that, elastic waves are capable of propagating through opaque substances such as human bodies, metals, and concrete blocks, in which light does not propagate. This means that physical quantities within these objects can be spatiotemporally modulated via ultrasonic excitation. Another is that, owing to the remarkable difference between the sound and the light velocities, elastic waves are featured by remarkably short wavelengths, being by about five digits smaller than those of electromagnetic (EM) waves. It follows that sharp focusing on a millimeter/ micrometer scale is achievable in the megahertz/gigahertz range where real-time waveform analysis is performed in commercially available equipments. Conventional ultrasonic measurements are intended to acquire mechanical properties such as elasticity or mass density. In recent years, however, we reported a nondestructive method in which EM properties of various objects are obtained through the measurements of acoustically stimulated EM (ASEM) responce[1].

In this paper, we demonstrate how magnetic properties are assessed by measurements of ASEM response. First, the orientation of alternating magnetic fields, induced by acoustically stimulated magnetic modulation, is investigated in a typical magnetic material (commercial ferrite magnet, $SrO/6Fe_2O_3$). Next, as one of industrial applications, metal embrittlement inspection of austenitic stainless steels (SUS304) is performed through the ASEM method.

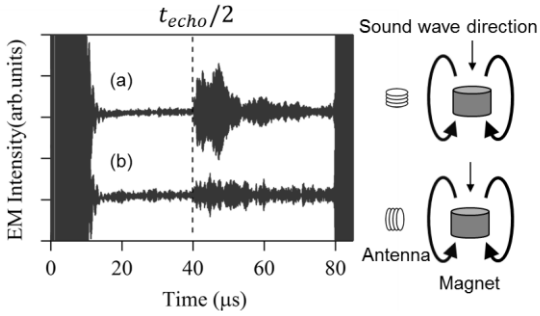

Fig. 1 Real-time waveform of ASEM response from a ferrite magnet.

2. ASEM method

In ASEM measurements, a target sample is placed in a focused zone at a distance (about 35 mm) from a 10 MHz transducer, in which rectangular 50 ns wide pulses are applied by a pulser/receiver (Panametrics-NDT, 5077PR). An appropriate distance between the sample and the transducer allows us to temporally separate the pulsed ASEM signals from EM noise generated by the transducer (Fig.1), resulting in high sensitive detection. The ASEM signals are obtained at a half of echo delay time t_{echo} and detected by a loop antenna tuned into a center frequency of ultrasonic waves. These signals are fed to low-noise preamplifiers (NF, SA-230F5) and averaged by using a digitizer. Rising pulse repetition rate results in shorter measurement time. The repetition rate is typically 200 Hz when a standard digital oscilloscope is used because its limit is determined by the processing capability of waveform analysis in the digitizer. We here construct, a waveform acquisition system based on a high-speed digitizer (National Instruments, PXI-5105), achieving a 2 kHz repetition rate.

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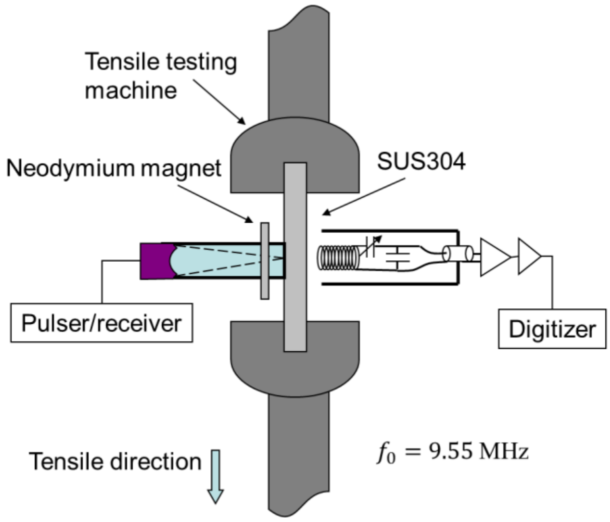

Fig.2 Schematic diagram of measurement setup.

3. Experimental Results and Discussion

First, ASEM response is studied in a commercial pillar-shaped ferrite magnet ($SrO/6Fe_2O_3$, 20 mm in diameter, 5 mm in thickness). As shown in Fig. 1, the wave vector *k* of longitudinal ultrasonic wave is parallel to the orientation of static magnetic field produced by the permanent ferrite magnet. We measured the acoustically modulated magnetic fields by using two different configurations of loop antenna (see the right panel of Fig.1). It is found that ASEM signals are significantly larger when the antenna is placed so as to detect magnetic field lines produced by the magnet, suggesting direct modulation of residual magnetization via acoustic excitation.

Next, we detect the stress-induced magnetization of austenitic stainless (SUS304) by using the ASEM method. It is known that external stress induces magnetization accompanied by martensitic transition[2-4]. With a tensile testing machine, in-situ observation of martensitic transition in a SUS304 specimen (10.0 mm in width, 1.87 mm in thickness) is demonstrated (Fig.2). An ultrasonic probe with an acoustic media is placed in contact with the surface of the specimen, and a resonant antenna tuned at a frequency of f_0 = 9.55 MHz is set on the opposite side. In order to align magnetization, a static magnetic field is applied by a neodymium magnet. As shown in Fig.3, ASEM response increases with increasing tensile stress. Its behavior exhibits a critical stress P_c of about 400 MPa, which is consistent with results reported in an earlier study[4].

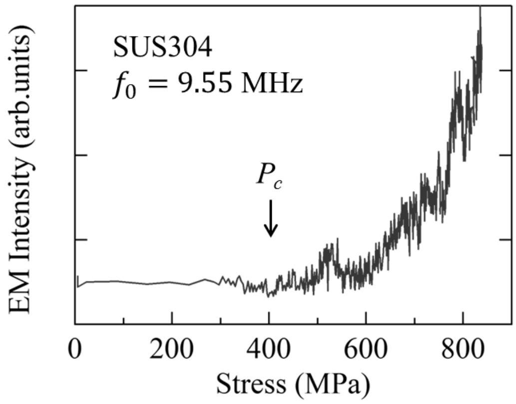

Fig.3 ASEM intensity as a function of tensile stress. The arrow indicates the critical value estimated from data of Ref.4.

4. Conclusion

We have performed magnetic measurements via ultrasonic excitation. By means of a high-speed data acquisition system, the measurement time is reduced by a factor of 10. We found that larger ASEM signals are obtained in a ferrite sample when the antenna is placed so as to detect magnetic field lines produced by the magnet. This suggests that residual magnetization components of the permanent magnet are modulated by ultrasonic waves. we also demonstrate in-situ observation of martensitic transition of austenitic stainless steels, allowing us to expect an application to visualization of metal embrittlement. It is worth noting that this sensitive experiment is implemented without shielded even in a noisy factory environment if the ground line and shield room of antenna are prepared with careful attention.

Acknowledgment

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