Available online at www.sciencedirect.com
ScienceDirect
NDT&E International 41 (2008) 108–111
NDT&E international
www.elsevier.com/locate/ndteint

Difference in the detection limits of flaws in the depths of multi-layered and continuous aluminum plates using low-frequency eddy current testing

Hironobu Yamada*, Teruki Hasegawa, Yudai Ishihara, Toshihiko Kiwa, Keiji Tsukada

Graduate School of Natural Science and Technology, Okayama University, 3-1-1 Tsushima-naka, Okayama 700-8530, Japan

Received 19 April 2007; received in revised form 31 August 2007; accepted 31 August 2007
Available online 7 September 2007

Abstract

We examined the difference in the detection limits of flaws in the depths of multi-layered and continuous aluminum plates using low-frequency eddy current testing. The detection limits were measured by using a magneto-resistive sensor. Comparing the frequency of an applied magnetic field, the detection limit at 50 Hz is deeper than that at 1 kHz. Comparing the sample structure, the detection limit in the multi-layered samples is deeper than that in the continuous samples. These results are likely due to the differences in the skin depth and conductivity of the sample.

Keywords: Non-destructive testing; Eddy current testing; Low-frequency magnetic field; Magneto-resistive sensor

1. Introduction

Non-destructive testing (NDT) is an important technique in engineering. There are many methods of NDT, for example, radiography, ultrasonic testing, magnetic particle examination, penetrant testing, and eddy current testing (ECT).

ECT is a method of examining defects mainly in metal. This measures the magnetic field caused by the eddy current induced by exposure to alternating magnetic fields. ECT is generally used with high-frequency magnetic fields, above kilohertz order, or search coils [1–3]. High-frequency magnetic fields are suitable for identifying surface defects, since skin depth δ is roughly inversely proportional to the root of operation frequency f. For example, the skin depth in infinite half-space is expressed as follows:

$$\delta = \frac{1}{\sqrt{\pi\mu\sigma f}}, \qquad (1)$$

where μ and σ are magnetic permeability and conductivity, respectively. In order to apply ECT to examining defects in depths, it is necessary to use a low-frequency magnetic field. However, it is difficult to sense a weak signal due to a defect by using a low-frequency magnetic field because the sensitivity of the search coil is not very high. For this reason, other sensitive sensors for weak magnetic fields are desired.

A superconducting quantum interference device (SQUID) is the most sensitive magnetic sensor and enables ECT to be conducted by using a lower frequency magnetic field [4–7]. However, SQUID generally needs a circumstance-magnetic shield to reduce ambient magnetic noises because of the high sensitivity and low dynamic range, and also needs to be cooled down to below the critical temperature.

Some groups have proposed a system for testing defects using magneto-resistive (MR) sensors [8–10]. Although an MR sensor is less sensitive than a SQUID, it is possible to measure a relatively weak magnetic field without a circumstance-magnetic shield and cooling.

Recently, we developed a system for testing defects in samples by using a low-frequency magnetic field, an MR sensor, and a lock-in amplifier [11]. This system has sensitivity of sub-nanotesla order in a non-shielded environment.

*Corresponding author.
E-mail address: hyamada@elec.okayama-u.ac.jp (H. Yamada).

0963-8695/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ndteint.2007.08.004

We also examined difference in the results of the testing by the structure of the sample or the frequency of the applied magnetic field from the magnetic components perpendicular to the applied magnetic field [12]. A flaw in the depth of a continuous sample is more difficult to detect than that of a multi-layered sample because of the weak signal.

In this study, we examined the magnetic component parallel to the applied magnetic field. We also examined the difference in the detection limits of flaws in the depths caused by differences in the structure or the frequency of the applied magnetic field.

2. Experimental

The apparatus consisted of an applying coil (diameter: 800 mm, number of turns: 40), a canceling coil (diameter: 10 mm, number of turns: 10), an MR sensor, a lock-in amplifier, and an alternating current source (AC source), arranged as shown in Fig. 1. The applying coil is for applying an alternating magnetic field to the sample. The canceling coil is for removing the influence on the sensor of the magnetic field caused by the applying coil. These coils are connected to the AC source, and the directions of turn are opposite. The lock-in amplifier with the MR sensor is also connected to the AC source. The signal detected from the sample, which includes the magnetic field strength and phase, is referred to that of the alternating current source. In this experiment, aluminum plates of 50 mm × 100 mm whose thickness varied were used as samples. In measuring the multi-layered sample, aluminum plates whose thickness is 1 mm are piled. On the bottom-side surface of each sample, an artificial discontinuity of 25 mm × 1 mm × 1 mm was mechanically made as shown in Fig. 2. This means that if the sample thickness is 3 mm, the distance from the upper-side surface to the top of the flaw is 2 mm. In measuring the multi-layered sample, a plate with a penetrating flaw and some normal plates were used.

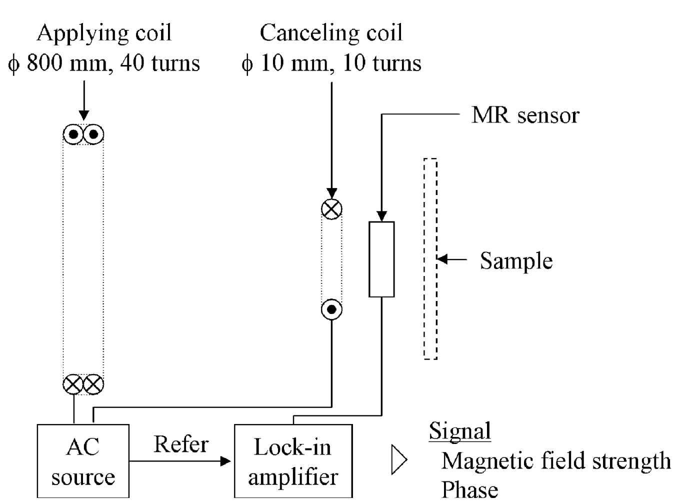

Fig. 1. Schematic drawing of the experimental apparatus.

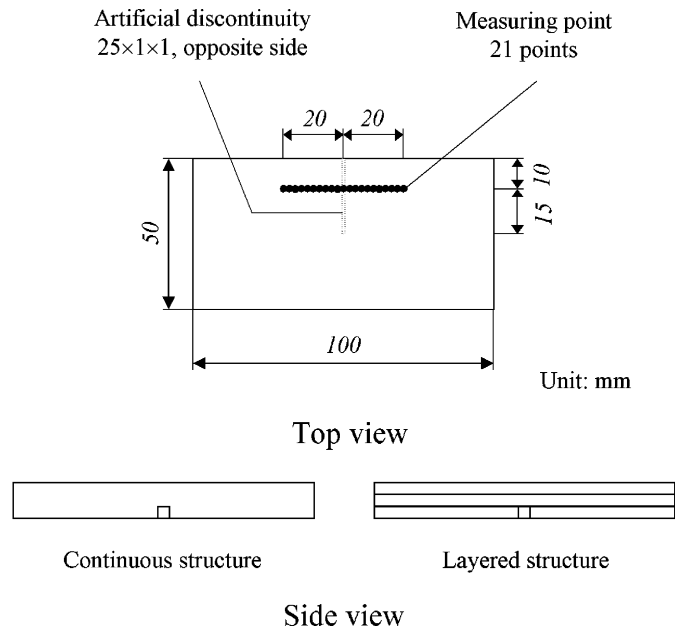

Fig. 2. Schematic drawing of the sample. The measuring points are shown as 2-mm-spaced dots.

The experimental procedure is as follows. First, detaching the sample from the apparatus, alternating current is applied to the applying coil, whose current and frequency are 1 A and 50 Hz or 1 kHz, respectively. Next, in order to reduce the applied magnetic field around the sensor, the canceling coil is moved along the direction of the center axis of the applying coil. Then, the sample is attached in the position as shown in Fig. 1. The flawed surface is the opposite side to the sensor. The distances from the non-flawed sample surface to the applying coil and the sensor are 535 and 1 mm, respectively. After that, the magnetic field of the eddy current caused by applying the magnetic field is measured with the MR sensor. The measured magnetic field is perpendicular to the sample surface. Measurement is performed ranging within 40 mm with 2 mm spacing. The measuring points are shown in Fig. 2 as dots. Here, the position of the center point, corresponding to the position at which the flaw exists, is defined as $x = 0$ mm.

3. Results and discussion

Fig. 3 shows the distribution of the magnetic flux density measured from the multi-layered samples whose thicknesses range from 2 to 8 mm in an applied magnetic field of 1 kHz. In a 2-mm-thick sample, the measured magnetic flux density decreased around the position of 0 mm, where the flaw exists. This decrease in magnetic flux density can be seen in the 7-mm-thick sample. The decrease in magnetic flux density around the region where the flaw exists may be caused by the difference in conductivity. From Maxwell's equation, the eddy current is expressed as

$$\vec{\nabla} \times \vec{J} = -\sigma \frac{\partial \vec{B}}{\partial t}, \tag{2}$$