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Inspection of the physical contact between two steel sheets by means of a potential drop technique

Hironori Tohmyoh [a,*], Hidetomo Ikarashi [a], Yuta Hasegawa [b], Satoshi Obara [b], Yoichi Matsui [b]

[a] Department of Nanomechanics, Tohoku University, Aoba 6-6-01, Aramaki, Aoba-ku, Sendai 980-8579, Japan
[b] Toyota Motor East Japan, Inc., 1 Nishinemoriyama, Kanegasaki, Iwate 029-4503, Japan

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ABSTRACT

In this paper, we propose a potential drop technique for inspecting the physical contact between two steel sheets. One of the important targets in this study is the examination of spot welds in the steel sheets and we evaluated this using the electrical circuit in a welding machine. First, we used numerical analysis to analyze the changes in the potential drop due to the size of the physical contact between the steel sheets. In the conventional setup for spot welding, two steel sheets are inserted between two Cu electrodes. In the analysis, the current is supplied through two terminals, one on the surface of each electrode, and the potential drop is measured between two other terminals, again, one on the surface of each electrode. The validity of the analysis was confirmed experimentally where the physical contact between the steel sheets was modified by inserting shims between the sheets.

1. Introduction

Steel sheet is widely used as a structural material in construction, and in the manufacture of automobiles, consumer electronics, etc. To join steel sheets together, resistance spot welding is normally used because the welding technique has great advantages compared with other methods in terms of speed, cost, etc. For example, several thousand spot welds are used in manufacturing an automobile and the quality of the spot welds is very important [1]. In particular, the size of the weld is an important parameter because it is closely related with its strength [2,3]. Therefore, understanding the condition of the physical contact between the steel sheets is a key element for ensuring the reliability of industrial products.

Several techniques for evaluating the quality of spot welds have been reported. Ultrasonic techniques are widely used in industry and various spot weld parameters, e.g. the nugget size, can be evaluated using ultrasonic Lamb waves [4] and the echoes reflected by the welds [5–9]. The potential drop technique, where a current is supplied to the sample to be tested and the potential drop on the surface of the sample is measured, can also be used to characterize welds [10,11]. Moreover, the quality of spot welds can be evaluated by X-ray [12] and magnetic flux leakage methods [13].

Although the above mentioned techniques are very useful for evaluating the quality of spot welds, these require precise positioning of the sensors or probes. Normally, it takes several seconds to complete one spot weld. However, positioning the sensors is time-consuming and these techniques cannot be applied practically to in-line inspection. Thus, at present, the quality of spot welds is guaranteed by precisely controlling three important parameters; the welding current, the time for current supply and the force applied to the electrodes. In order to monitor the quality of welds, the strength of selected spot welds is checked by a destructive method with a chisel.

In this paper, we propose a potential drop technique which can be realized using the electrical circuit used in welding. We investigate an effective way to analyze the physical contact between two steel sheets numerically, and the validity of the proposed technique is verified experimentally.

2. The potential drop technique

The potential drop technique has been widely used in materials evaluation, e.g., for evaluating cracks [14,15], measuring the electrical conductivity of materials, etc. Closely coupled probes, in which there are two probes for supplying current and two for measuring the potential drop, have been developed and the precise measurement of cracks has been realized with compact probes [16,17]. Although the nugget size of spot welds can be

* Corresponding author.
E-mail address: tohmyoh@ism.mech.tohoku.ac.jp (H. Tohmyoh).

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evaluated using similar types of probes [10], the time required to manipulate the probes is a limitation for in-line inspection. The quality of microwelds has been evaluated by the potential drop technique performed under microscopic observation [18]. In this study, we propose a new type of potential drop technique which utilizes the electrical circuit used for welding. Thus, the setup can be embedded in the welding machine.

2.1. Procedure for numerical analysis

Here we use finite element analysis (FEA) to analyze the physical contact between two steel sheets by means of a potential drop technique. One of the primary targets is evaluation of the nugget size of conventional spot welds, and we consider that this can be realized with our experimental setup embedded in a welding machine. The sample to be tested is inserted between two Cu electrodes and the current is supplied to the sample via the electrodes. Changes in the potential distribution around the electrodes due to the physical contact between the two steel sheets were investigated numerically.

The current flow in a material is governed by the Laplace equation, and the electrical potential φ is given by

$$\Delta\varphi = 0, \qquad (1)$$

where Δ is the 3-D Laplace operator. The Laplace equation can be solved by FEA, and φ is numerically determined. In this study, the non-linear analysis program Marc was used for FEA. The geometry and dimensions of the 1/2 FEA model used are shown in Fig. 1. A 0.7 mm thick Fe disc with diameter C is inserted between two 17.5 mm diameter and 1.2 mm thick circular sheets of Fe. Pressed into each side of the sample are columnar Cu electrodes with diameter D and length 20 mm. In these analyses, the values of C ranged between 1 and 6 mm, and those of D between 3 and 9 mm.

The electrical resistivity of Cu is 1.68×10^{-8} Ω m, and that of Fe is 1.42×10^{-7} Ω m. The contact resistance between the Cu electrodes and the Fe sheets was assumed to be constant at 6.0×10^{-6} Ω m, and that between the Fe disc and the Fe sheets was assumed to be zero. The current input and output are each located 4 mm away from the surface of one of the Fe sheets. The current supplied in each FEA was 1 A. The x axis is placed along the surface of the Cu electrodes on the sides on which the current input and output are located, with the origin midway between the two Fe sheets. The potential, φ, along the x axis was determined.

2.2. Results of numerical analysis

The distribution of the current density in the cases of C=3 and 6 mm is shown in Fig. 2(a) and (b), respectively. Here, the Cu electrode diameter, D, was 6 mm in both cases. We can see that a

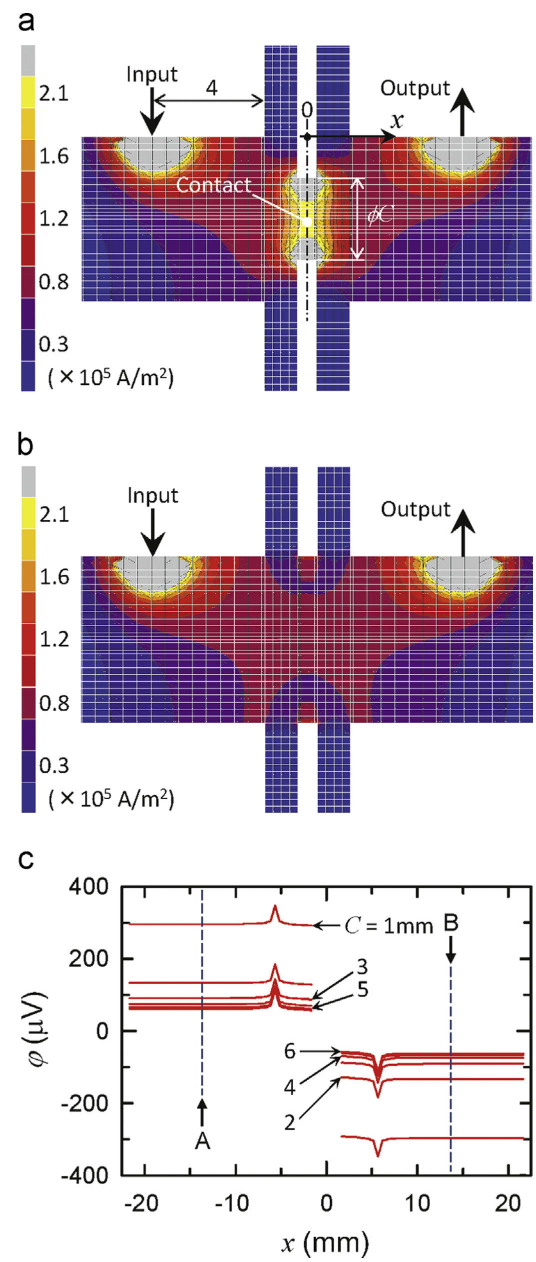

Fig. 2. (a) Current density distributions for (a) C=3 mm, and (b) C=6 mm. Here D is 6 mm. (c) The relationships between φ and x for various values of C.

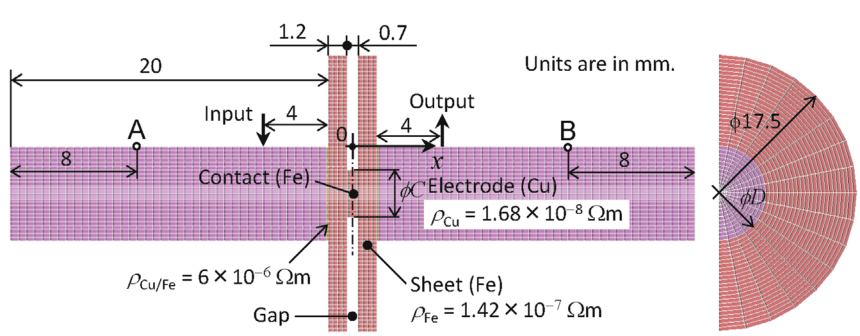

Fig. 1. FE model together with the dimensions. Cylindrical Cu electrodes with diameter D and length 20 mm, and circular Fe sheets with diameter 17.5 m and thickness 1.2 mm are considered. Here 0.1 mm thick contact layers are inserted between the electrodes and the sheets and the contact resistance between them is considered. The physical contact between the sheets is 0.7 mm thick and has diameter C.