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Influence of Electrode Pressure and Welding Conditions on the Maximum Tensile Shear Load*

– Study on the Development of Electrode Force Changeable Lap Resistance Spot Welding Machine and Characteristics of Welds (Report 2) –

by FURUKAWA Kazutoshi**, KATOH Mitsuaki***, NISHIO Kazumasa*** and YAMAGUCHI Tomiko***

Lap resistance spot welding was performed on cold rolled steel (SPCC) with an electrode force changeable lap resistance welding machine the authors had developed. We evaluated the welds by ultrasonic testing (immersion method, C-scope representation) and a tensile shear test, and compared the results for this method with those by the conventional method. It was useful to apply the ultrasonic testing to evaluate the welds. Usually plug-type fracture was observed in the tensile shear test and the maximum tensile shear load was larger than those estimated using the value of the minimum strength (290 MPa) of SPCC specified by the Japanese Industrial Standard, though some specimens fractured along the weld interface. Regression analysis was performed by setting the maximum tensile shear load as a dependent variable, and setting the initial electrode force, the welding current, the initial electrode force timing and the latter electrode force as independent variables. The result shows that only the initial electrode force and the welding current were significant. The maximum tensile shear strength increased by increasing the welding current and decreasing the initial electrode force. It was made clear that we could obtain better spot welds by using the process we developed than the conventional spot welds.

Key Words: Electrode force changeable lap resistance welding machine, Ultrasonic testing, Plug-type fracture, SPCC, Regression analysis, Initial electrode force, Welding current

1. Introduction

In lap resistance spot welding, generally, the welding is performed by applying the preset welding current for a certain time under the constant preset electrode force[1]. It might be possible to obtain different weld properties from those by the conventional method when we change electrode force (referred to as force) during and after the welding.

In the report 1 an apparatus for varying a force of a spot welding machine the authors had developed was applied on cold rolled steel (SPCC) and temporal changes of the force were compared with those by a conventional process[2]. We obtained weld joints under the constant base force, and by changing initial electrode force (referred to as initial force and this was mainly applied during the current-on; changed three levels), latter electrode force (referred to as latter force and this was applied after the current-off; changed three levels), initial electrode force timing and welding current. The results show that we could obtain good welds by smaller welding current than the conventional one and large maximum tensile shear load by using this apparatus.

In this study we evaluated the welds obtained using this apparatus by ultrasonic testing (immersion method, C-scope representation) and a tensile shear test, and compared the results for this method with those by the conventional method.

2. Material Used and Experimental Procedures

A material used is cold rolled steel (SPCC, thickness:1 mm) whose chemical composition are 0.05 C, 0.18 Mn, 0.01 P, 0.01 S and Fe (balance) in mass % (specified tensile strength and elongation are more than 290 MPa and 37%, respectively). Figure 1 shows shape and dimensions of a specimen to be welded whose width and length are 50 and 100 mm, respectively. The lap length was set to be 50 mm and spot welding was performed in the center of the lap region (tip diameter of the electrode: 5 mm). A tensile shear test was performed to measure the maximum tensile shear load on the weld joints as welded by using an in-house made machine whose maximum tensile load was 50 kN.

A method of ultrasonic testing used in this study is C-scope representation by immersion method as shown in Fig.2. In this method ultrasonic waves are transmitted into a specimen to be tested through water. We can receive reflected waves from a weld interface if the welds are not good. If we have good welds we can receive reflected waves from a back wall of the specimen without

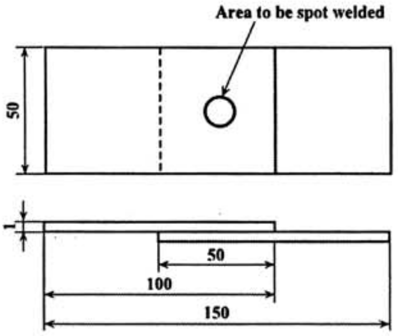

Fig. 1 Shape and dimensions of a specimen for spot welding

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waves from the interface. Hence, it is possible to evaluate the welds by images constructed through the ultrasonic testing when we set a gate near the weld interface and obtain reflected echoes from this region. The images were obtained by scanning a probe front and back or right and left at a pitch of 0.10 mm and were represented by colors.

3. Welding Conditions and their Representation Method

Figure 3 (a) and (b) show schematic illustrations of the temporal change of the force for the constant force and in varying force, respectively. Figure 3(a) is the conventional process and base force, that is, the force before the welding was set to be 3 kN (this is the standard value and represented as 100). Welding current was changed to be I=6.0, 6.5, 7.0, 7.5, 8.0, 8.5 and 9.0 kA, and weld time was kept constant to be 8 Hz.

In Fig.3 (b), the force decreased less than the base force (called initial force, P_1) to be 40% (1.2 kN, represented to be 40), 60% (1.8 kN, 60) and 80% (2.4 kN, 80). The force after the welding, called latter force (P_2), were changed to three levels of 100% (3.0 kN, 100), 120% (3.6 kN, 120) and 140% (4.2 kN, 140). Moreover, the initial force timing was changed to three levels of t_p=0 Hz (the force was applied at the same time of the current-on, represented to be 0), − 1 Hz (the force was applied before 1 Hz of the current-on, − 1), and − 2 Hz (the force was applied before 2 Hz of the current-on, − 2). Welding current was changed to be I=6.0, 6.5, 7.0, 7.5 and 8.0 kA, and the weld time was kept constant to be 8 Hz. The time duration of the latter force after the current-off was set to be about 16 to 24 Hz.

The welding conditions are represented in turns of the current timing, the initial force and the latter force. For example, in the conventional process we should represent 0-100-100 since t_p=0 Hz and there is no change in the force. When we change the force we should represent − 1-40-120 for the case of t_p= − 1 Hz, P_1=40 and P_2=120. In the latter case we performed welding using 27 conditions since we changed the initial force timing, the initial

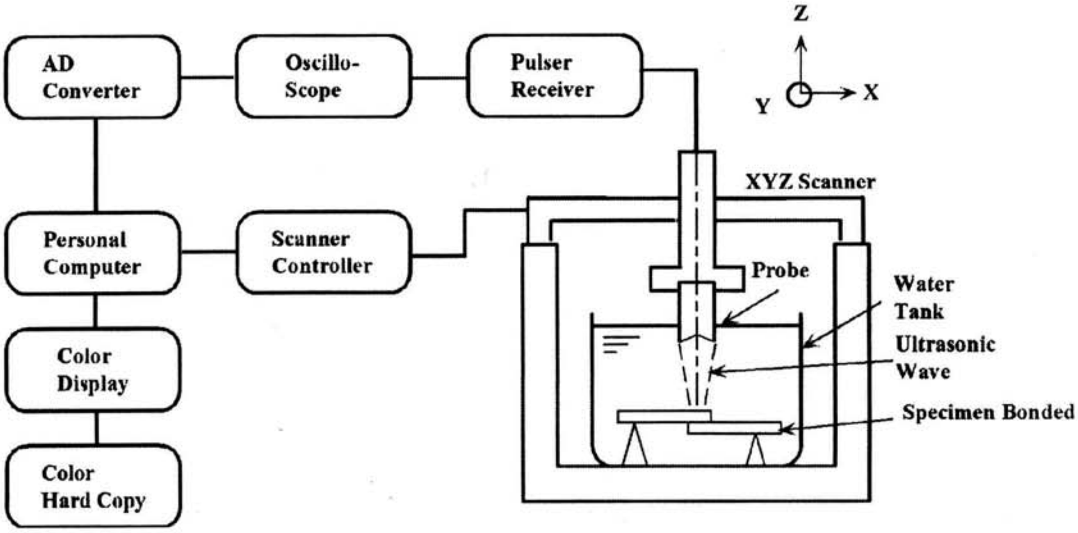
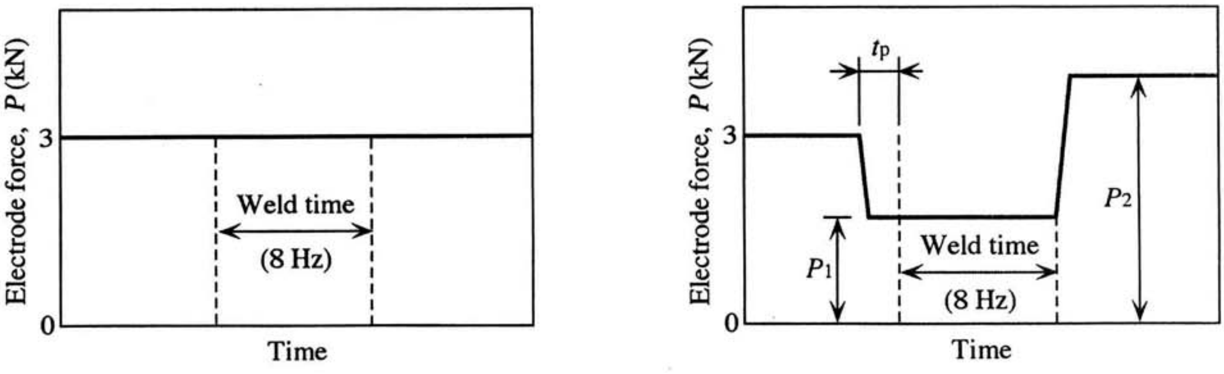


Fig. 2 Block diagram of equipment of ultrasonic



(a) Constant electrode force

(b) Varying electrode force

Fig. 3 Schematic illustration of the temporal change of electrode force

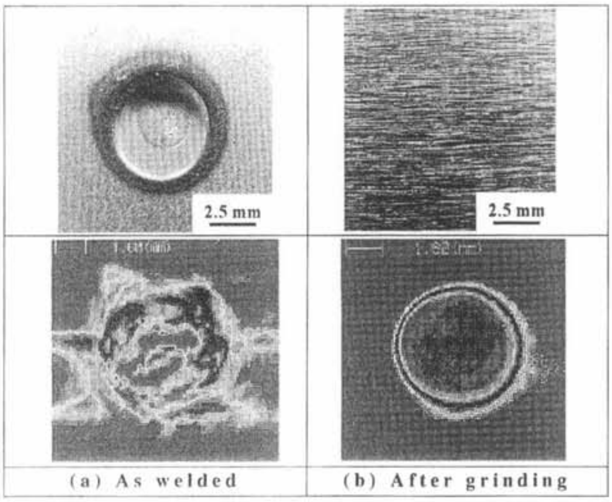
force and latter force in three levels, respectively.

For each welding condition we obtained 5 weld joints.

4. Evaluation of Welds by Ultrasonic Testing

Figure 4 shows the comparison of C-scope images as welded with that after grinding the surface of the welds in 0-100-100 when I =7.5 kA. We can see a fairly deep dent on the surface as welded. As is seen in Fig.4 (a) we could not obtain a clear image from the welds as welded because ultrasonic waves were scattered near the dent, but could obtain a clear image after grinding the surface as is seen in Fig.4 (b). Hence the ultrasonic testing was performed on the welds after grinding flatly the surface of the welds in this study.

Since the images are digitalized in 256 steps in the equipment used it is possible to binalize the images when we set a threshold level. We obtained the ratio of good welded area to the spot welded area by this method. Figure 5 shows the relation between the ratio of good welded area and the threshold level in 0-100-100 when I =6.0 kA. The ratio of good welded area increases with the increase in the threshold level and tends to saturate. When there is a little reflection of ultrasonic waves from the welds height of reflected echo is low, and vice versa. Hence when we choose the smaller threshold level the ratio of good welded area becomes smaller since we select even lower height echoes as flaws. It is necessary to choose the proper threshold level. In this study we judged the region where ductile fracture was observed in a tensile shear test of the weld joints as the good welded area. That is, we observed the fracture surface fractured along the interface after the tensile shear test with SEM and drew the boundary between the region where dimple patterns were observed and the region where no dimple pattern were observed. Since we can draw contour map depending on the threshold levels by the ultrasonic testing we can select the best threshold level which has the best correspondence between them and we could obtain the threshold level of 140.



(a) As welded (b) After grinding

Fig. 4 Comparison of C-scope images as welded with that after grinding the surface in 0-100-100 when I =7.5 kA

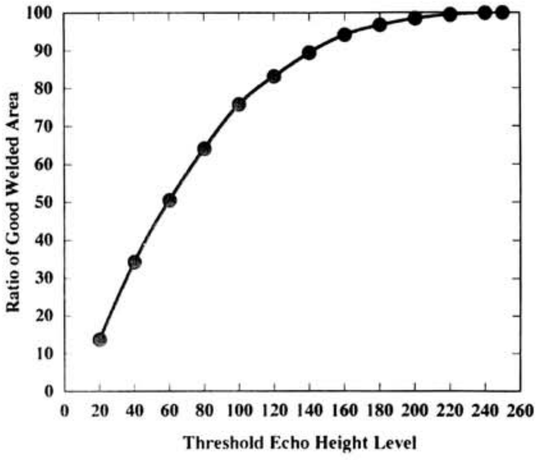


Fig. 5 Relation between the ratio of good welded area and threshold level in 0-100-100 when I =6.0 kA

In 0-100-100 the ratio of good welded area was about 90% when I=6.0 kA. The ratio increased with the increase in the welding current and reached approximately 100% when I=7.5 and 8.0 kA. Similar tendency was obtained when we applied the initial force and the ratio of good welded area increased with the decrease in the initial force at the same welding current. That is, we could easily obtain the good welds even in a smaller welding current when we applied smaller initial force.

5. Influence of Welding Conditions on the Maximum Tensile Shear Load

Mechanical properties of the welds were evaluated by performing a tensile shear test on the weld joints. Some weld joints fractured along the weld interface but most of the joints experienced plug-type fracture. Figure 6 shows the appearance of

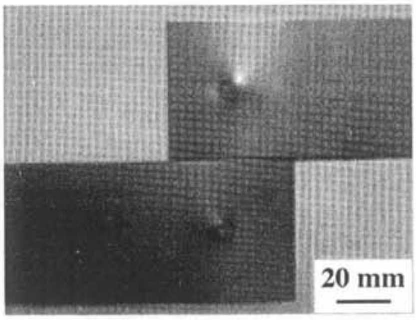


Fig. 6 Appearance of a weld joint fractured along the weld interface

a weld joint fractured along the weld interface. Figure 7 (a) and (b) show appearances of weld joints of plug-type fracture when the fracture just occurred and after the fracture.

The maximum tensile shear load F_{max} (N) when plug-type fracture occurred is given by Eq.(1) based on the experimental results[3].

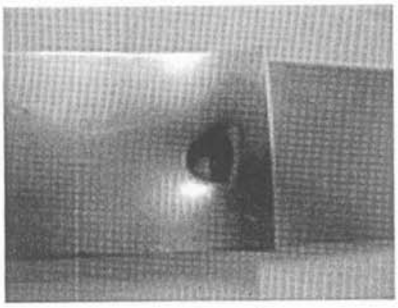
$$F_{max}=At\,d_n\,\sigma_B \qquad (1)$$

where t : thickness of the specimen (mm), d_n : nugget diameter (mm), σ_B :tensile strength of the material (MPa) and A : constant (given as approximately 3). We can obtain the value of F_{max} = 4350 N when we substitute $t = 1$ mm, d_n=5 mm and $\sigma_B = 290$ MPa (the minimum tensile strength of SPCC specified in The Japanese Industrial Standard). Hence we can satisfy the minimum requirement of the strength SPCC should have if the maximum tensile load of the welds is larger than 4.4 kN.

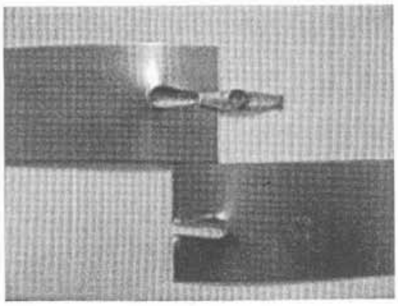
5.1 Influence of initial electrode force

The influence of the initial force on the maximum tensile shear load were examined when P_I=40, 60, 80 and 100 (the value of 100 corresponds to the conventional process). The latter force was kept to be 100. Figure 8 shows the influence of the initial force on the relation between the maximum tensile shear load F_{max} (kN) and the welding current. In every initial force F_{max} increased with the increase in the welding current and tended to saturate when the welding current was larger than about 7 kA. When P_I<100 the maximum welding current was set to be 8.0 kA since F_{max} in P_I =100 decreased a little when I=8.5 and 9.0 kA. The important phenomenon in Fig.8 is that F_{max} when P_I <100 increased in every welding current than that when P_I =100. The difference between them is significant when the welding current is small. Though the fracture along the weld interface was observed only when P_I=100 and I=6.0kA plug-type fracture occurred in other welding conditions. The condition F_{max} >4.4 kN was satisfied in Fig.8 except the case when the fracture along the weld interface was observed.

Figure 9 shows the influence of the welding current on the relation between the maximum tensile shear load and the initial force. When I=6.0 kA F_{max} increased abruptly from 1.3 to 4.7 kN with the decrease in P_I from 100 to 80, and increased gradually with the further decrease in P_I. This change decreased with the increase in the welding current and F_{max} tended to increase. When



(a) When the fracture just occurred



(b) After the fracture

Fig. 7 Appearance of weld joints of plug-type fracture

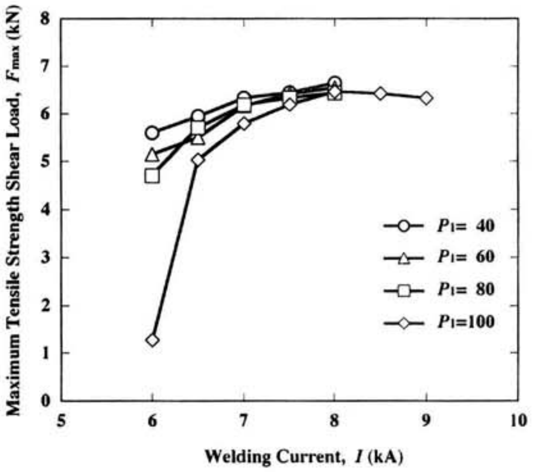


Fig. 8 Influence of initial electrode force on the relation between the maximum tensile shear load and welding current

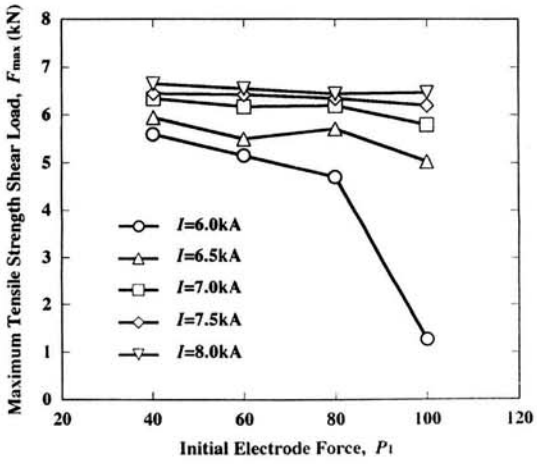


Fig. 9 Influence of welding current on the relation between the maximum tensile shear load and initial electrode force

I=7.5 and 8.0 kA F_{max} had approximately the same value independently of P_1.

Figure 10 (a) and (b) show the influence of the initial force on the relation between the maximum tensile shear load and the welding current when P_2=120 and 140, respectively. The qualitative change is similar as that in Fig.8.

5.2 Influence of initial electrode force timing

Figure 11 (a) and (b) show the influence of the initial force timing on the relation between the maximum tensile shear load and welding current when P_1 = 40 and 60, respectively (P_2=100). The timing t_p was 0, -1 and -2 Hz. In every case F_{max} tended to increase with the increase in the welding current independently of t_p.

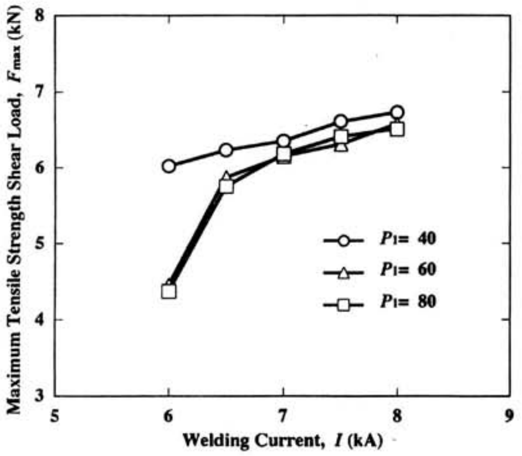
5.3 Influence of latter electrode force

Figure 12 (a), (b) and (c) show the influence of the latter force on the relation between the maximum tensile shear load and the welding current when P_1=40, 60 and 80, respectively. The change depends on the initial force. That is, when P_1=40 the influence of the welding current on F_{max} is small and F_{max} has large values 5.6 to 6.0 kN even when I=6.0kA. When P_1=60 the change in F_{max} with the increase in the welding current is larger than that when P_1=40. In the cases of P_1=40 and 60 the influence of the latter force is not clear. When P_1=80, however, the change in F_{max} with the increase in the welding current is larger and we can see the significant change when P_2=140.

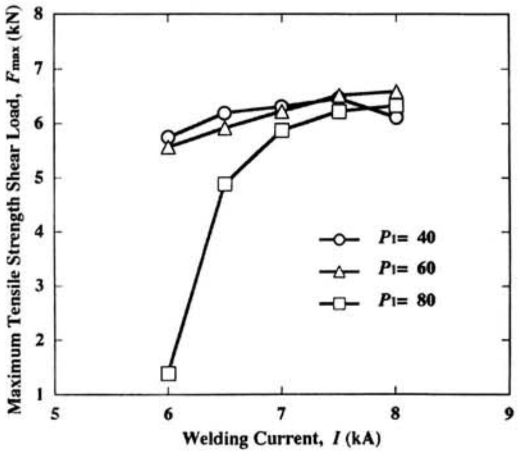
The results show that we can obtain stable and large maximum tensile shear load independently of P_2 by setting such a small initial force as 40.

6. Study by Regression Analysis

In section 5 we discussed the influence of welding conditions on the maximum tensile shear strength. The results showed that the influences of the welding current and the initial force were

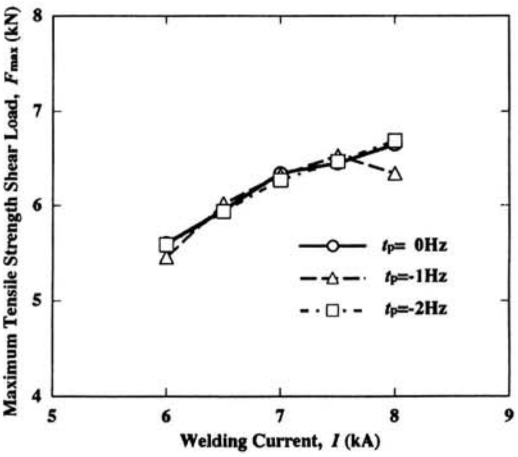


(a) P_2=120

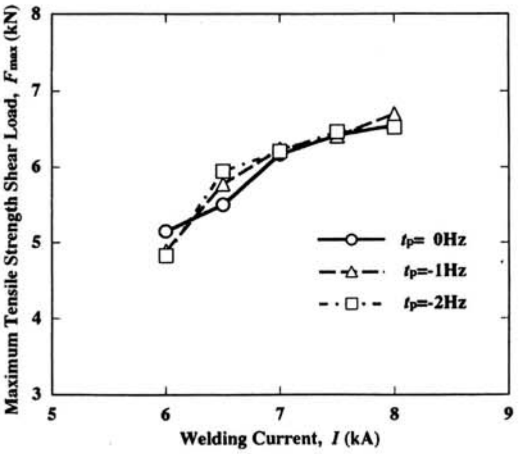


(b) P_2=140

Fig. 10 Influence of initial electrode force on the relation between the maximum tensile shear load and welding current when latter electrode force was changed



(a) P_1=40



(b) P_1=60

Fig. 11 Influence of initial electrode force timing on the relation between the maximum tensile shear load and welding current (P_2=100)

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