Relation between Welding Conditions and Temporal Change of Electrode Force

− Study on the Development of Electrode Force Changeable Lap Resistance Spot Welding Machine and Characteristics of Welds (Report 1) −

FURUKAWA Kazutoshi , KATOH Mitsuaki , NISHIO Kazumasa , YAMAGUCHI Tomiko

溶接学会論文集 第24巻 第1号 別刷

平成18年 2 月

[溶接学会論文集 第24巻 第1号 p.3-9 (2006)]

Relation between Welding Conditions and Temporal Change of Electrode Force*

– Study on the Development of Electrode Force Changeable Lap Resistance Spot Welding Machine and Characteristics of Welds (Report 1) –

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

The authors have developed an apparatus for varying an electrode force of a spot welding machine. This is equipped with a servomotor by which we can change rotation instantaneously from normal to reverse and vice versa, and also has a display by which we can monitor the change in the electrode force. Lap resistance spot welding was performed on cold rolled steel (SPCC) and temporal changes of the electrode force were compared with those by a conventional process. In the conventional process the electrode force changed complexly with the elapsed time and the changes were divided into three kinds depending on welding current. When we decreased the initial electrode force than that in the conventional process good welds could be obtained even in lower welding current and the decrease in the thickness of the welds could be lowered. In this case the temporal changes of the electrode force could be explained during the expansion and shrinkage of the welds, though the electrode force changed complexly depending on the initial electrode force and welding current.

Key Words: Electrode force changeable lap resistance welding machine, Temporal change of electrode force, Servomotor, SPCC, Initial electrode force, Welding current

1. Introduction

Electrode force, welding current and weld time are the three important elements in lap resistance welding[1]. So far many studies have been performed on the electrical elements such as welding current and welding time and the results have been summarized in handbooks and textbooks[2]. But little study has been performed on the mechanical element, that is, electrode force because of experimental difficulties, though this welding is called as the welding by applying pressure.

In general the welding is performed by applying current during the weld time set under the constant electrode force in lap resistance spot welding. Heating, fusion, solidification and cooling (transformation in some metals) occur in the welds during short time. The actual electrode force might change complexly with the expansion and shrinkage of a material welded, and hardness changes during welding. But little study has been performed on this. It should be possible to obtain different properties of the welds from those by the conventional process when we change the electrode force during and after the welding.

In this study we have developed an apparatus for varying an electrode force of a spot welding machine. This is equipped with a servomotor by which we can change rotation instantaneously from normal to reverse and vice versa, and also this has a display by which we can monitor the change in the electrode force (referred to as force). Lap resistance spot welding was performed on cold rolled steel (SPCC) and temporal changes of the force were compared with those by a conventional process. In changing the force, the influences of initial electrode force timing and of the latter electrode force (referred to as latter force) were also examined. Moreover, macro- and microstructures of the welds were observed and the relation between the maximum tensile shear load and welding conditions were studied by performing a tensile shear test on weld joints.

2. Setup for Changing Electrode Force

Figure 1 shows a setup of the apparatus including a device to change the force. The force, which was measured by a load cell, can be changed instantaneously by changing the rotation of the servomotor from normal to reverse and vice versa. The data on the monitor was taken in every 5 ms and represented on the display. The force necessary for use was set in the condition of no current to satisfy the fixed value and this was maintained as it was during the welding process, that is, a gap between electrodes of the machine was kept constant depending on the force. Hence, the actual force represented on the display changes due to the

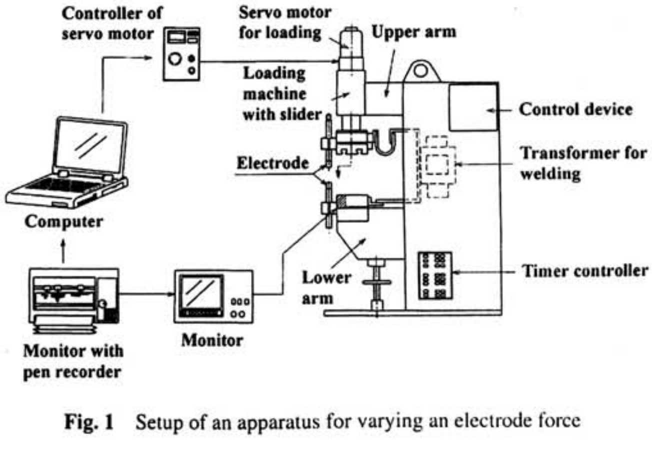


Fig. 1 Setup of an apparatus for varying an electrode force

*Recieved: 2005. 5. 19
**Member, Aichisangyo Co. Ltd.
***Member, Kyushu Institute of Technology

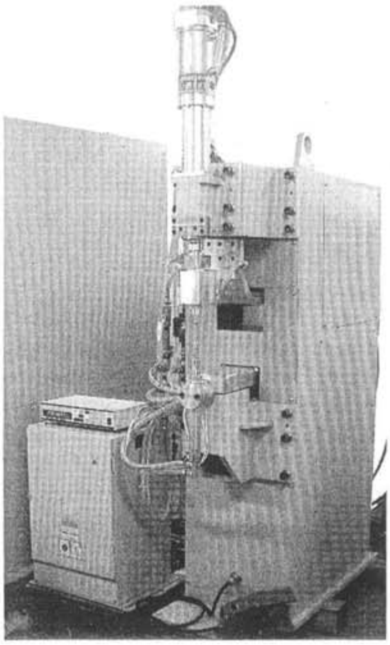


Fig. 2 Appearance of a resistance spot welding machine

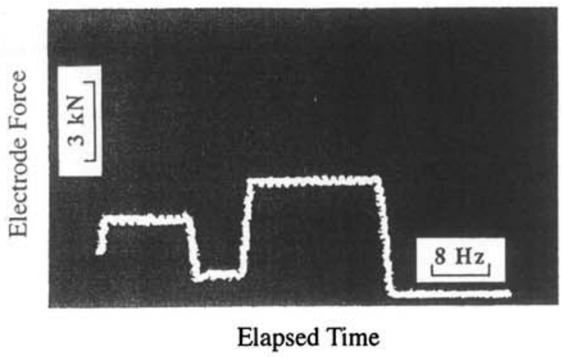


Fig. 3 An example of temporal changes of electrode force with no current

behavior (expansion due to heating, decrease in deformation resistance due to melting and shrinkage due to cooling) of the material during and after the welding. Figure 2 shows the appearance of the resistance spot welding machine.

Figure 3 shows an example of temporal changes of the force represented on the display when we set a preset force to be 3 kN, decreased the initial electrode force (referred to as initial force) to 1.2 kN instantaneously with the current-on (weld time:8 Hz) and increased the latter force to 4.2 kN instantaneously with the current-off. It was possible to change the force instantaneously, though it took some short time until the force reached the fixed value after applying the force.

3. 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

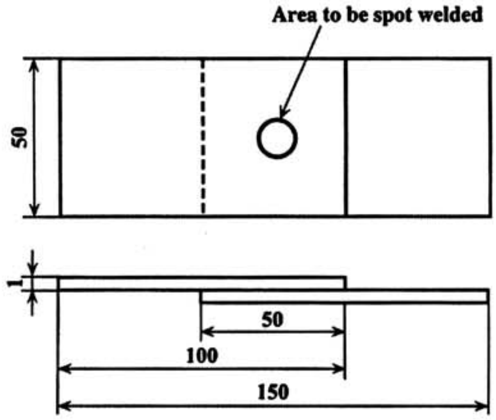


Fig. 4 Shape and dimensions of a specimen to be welded

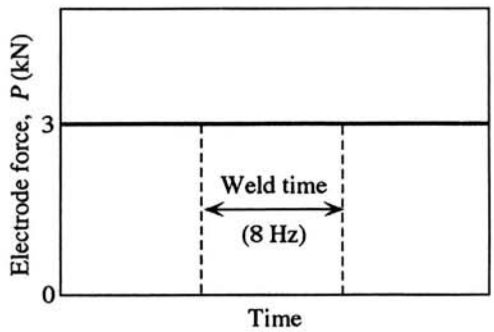
and Fe (balance) in mass % (specified tensile strength and elongation are more than 290 N/mm^2 and 37%, respectively). Figure 4 shows shape and dimensions of a specimen to be welded whose width and length are 50 and 100 mm, respectively. The lap length was set to be 50 mm and spot welding was performed 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.

Macro- and microstructures of the welds were observed after polishing the cross sections of the welds and etched the sections with nithal.

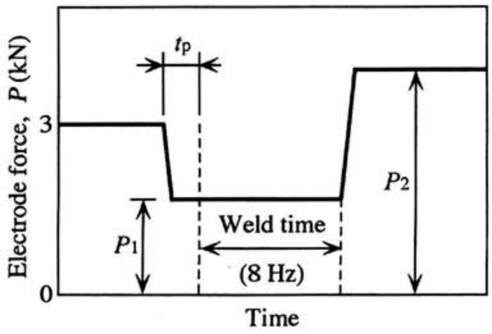
3. Welding Conditions and their Representation Method

Figure 5 (a) and (b) show schematic illustrations of the temporal change of the force for the constant force and in varying force, respectively. Figure 5(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.5 (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 initial force was applied at the same time of the current-on, represented to be 0), −1 Hz (the initial force was applied before 1 Hz of the current-on, −1), and −2 Hz (the initial 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

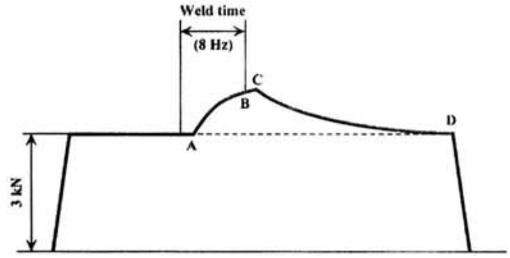


(a) Constant electrode force

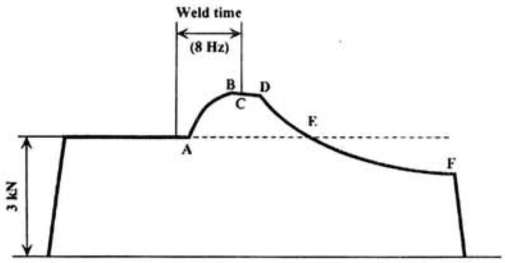


(b) Varying electrode force

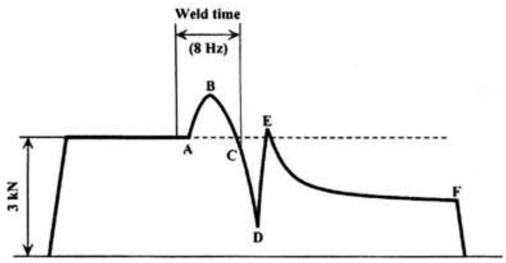
Fig. 5 Schematic illustration of temporal change of electrode force



(a) Type I (I=6.0 kA)



(b) Type II (I=8.0 kA)



(c) Type III (I=8.5 kA)

Fig. 6 Examples of temporal changes of electrode force in 0-100-100

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 case of 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 current timing, the initial and latter force in three levels, respectively.

For each welding condition we prepared 5 weld joints.

4. Experimental Results and Discussions

4.1 The case of the constant force

The temporal change of the force depended on the initial and latter force, the initial force timing and the welding current. The results were classified into three types as shown in Fig.6 (a), (b) and (c) (these are the results for 0-100-100). Figure 6 (a) is the case, designated type I, when the force increased with time, showed the maximum and after that decreased gradually (observed in I=6.0, 6.5 and 7.0 kA). Figure 6 (b) is the case, designated type II. In this case the force increased with time, showed the maximum, kept almost the same value and after that decreased gradually (observed in I=7.5 and 8.0 kA). Figure 6 (c) is the case, designated type III, when the force increased with time, showed the first maximum, then decreased abruptly, increased again and showed the second maximum, and after that decreased gradually (observed in I=8.5 and 9.0 kA).

Type I was observed when weld heat input was small (we use the term of weld heat input since the development of a nugget depends on the initial force as will be mentioned later for the same welding current). When the current is turned on the material is heated and the force increases as shown by the curve AB with the expansion of the material. Actually, however, there is some delay of about 0.5 Hz until the increase in the force starts as seen in Fig.6 (a). When the current is turned off the cooling does not necessarily starts immediately, the expansion continues for a while as shown by the curve BC and the force takes the maximum at the point C (the maximum value increased a little with the increase in the welding current but decreased when the weld heat input became too large). After that the cooling starts and the force decreased gradually with the shrinkage of the material as shown by the curve CD. The force at the point D was about 3 kN in I=6.0 kA and tended to decrease with the increase in the welding current. This is due to the phenomenon that the deformation of the material at the electrode tip increased with the increase in the welding current (macrostructures of the cross sections of the nuggets will be shown in 5.3).

Type II was observed when the weld heat input was medium. Though the qualitative tendency is similar as the type I, the different point is that the force takes the maximum at the point B and keeps almost the same value as shown by the line BCD. This is due to the phenomenon that the softening of the material begins with the increase in the weld heat input. The force begins to decrease from the point D with the cooling of the material as shown by the curve DEF and the force at the point F decreased to a value of 2.7 kN in Fig.6 (b).

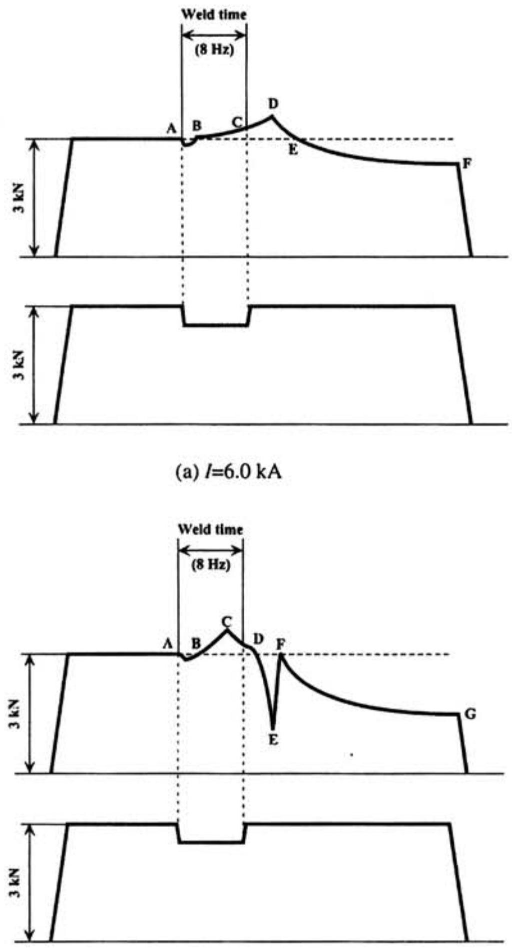
Type III was observed when the weld heat input was large. When the current is turned on the force increases with the expansion of the material and has the maximum at the point B. The material is softened, however, since the weld heat input is large. Hence the deformation resistance of the material becomes smaller and the force decreases abruptly as shown by the curve BC. This tendency continues for a while even after the current-off as shown by the curve CD. When the cooling of the material starts, the material becomes harder and the deformation resistance of the material becomes larger. Then the decrease in the force stops and the force changes to increase due to the reaction against the phenomenon so far as shown by the curve DE. After that the force decreased gradually similarly to the case of the type I and II as shown by the curve EF to the value of 1.5 kN in Fig.6 (c) while the preset force was 3.0 kN. This leads to the decrease in the thickness of the welds. That is, the thickness decreased to 1.5 mm in I=8.5 kA and 0.9 mm in I=9.0 kA though the original thickness was 2.0 mm (when the welding current was too large the decrease in the thickness also occurred due to the splash of the molten metal).

The maximum tensile shear load F_{max} were 1.3, 5.0, 5.8, 6.2, 6.5, 6.5 and 6.3 kN when the welding current I = 6.0, 6.5, 7.0, 7.5, 8.0, 8.5 and 9.0 kA, respectively. The maximum tensile shear load tended to increase with the increase in the welding current (the detail of the influence of the welding conditions on the maximum tensile load will be reported in the report 2).

4.2 The case in varying the force

The temporal changes of the force in this case were also classified into the same three types as the above though there were some differences in detail. First of all the cases of 0-80-100, 0-60-100 and 0-40-100 will be mentioned.

Figure 7(a) and (b) show the temporal changes of the force in

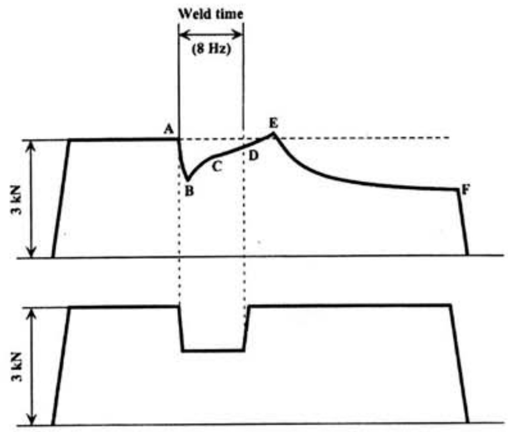


(a) I=6.0 kA

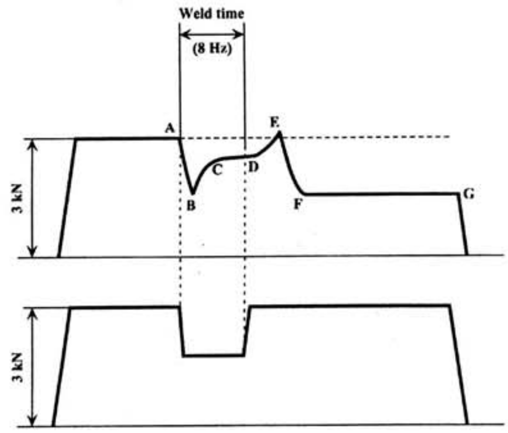
(b) I=8.0 kA

Fig. 7 Examples of temporal changes of electrode force in 0-80-100

0-80-100 when I=6.0 and 8.0 kA, respectively. By decreasing P_1 to 2.4 kN (80% of the base force) we can see the different change than that in 0-100-100 shown in Fig.6 (a). Since the force decreased instantaneously with the current-on we can see the change due to this as the curve AB. With the elapsed time the force increases gradually as the curve BCD (this change is the same as the case in 0-100-100). The maximum force corresponding to the point D, however, is a little smaller than the case in 0-100-100 and the force after the point E is smaller than 3 kN (the temporal change of the force is classified as type I). The maximum tensile shear load F_{max} in Fig.7 (a) was 4.7 kN, which was much larger than in the case shown in Fig.6 (a), F_B=1.3 kN). This is due to the fact that the fusion in the nugget in 0-80-100 was sufficient but not in 0-100-100. That is, the fusion in the nugget becomes easier by decreasing the initial force because contact resistance increases at the weld interface and hence generated heat amount increases. The decrease in the force due to the cooling of the material became significant with the increase in the welding current. When we increased the welding current to 6.5, 7.0 and 7.5 kA the maximum tensile shear load increased to

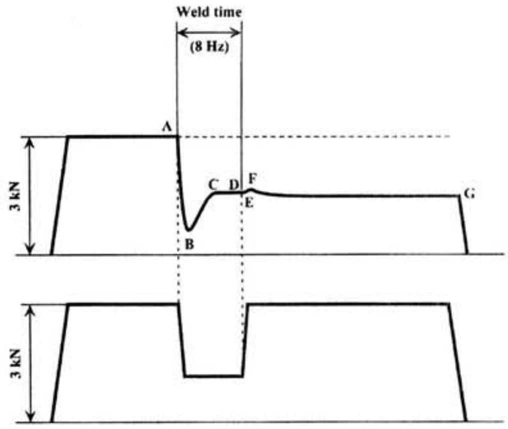


(a) I=6.0 kA

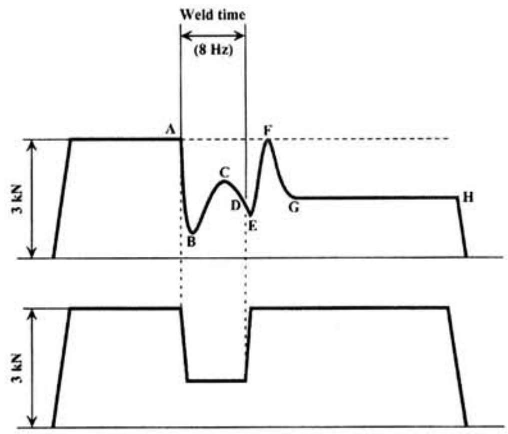


(b) I=7.5 kA

Fig. 8 Examples of temporal changes of electrode force in 0-60-100



(a) I=6.0 kA



(b) I=7.5 kA

Fig. 9 Examples of temporal changes of electrode force in 0-40-100

5.7, 6.2 and 6.3 kN, respectively (the temporal change of the force was also classified as type I in every case).

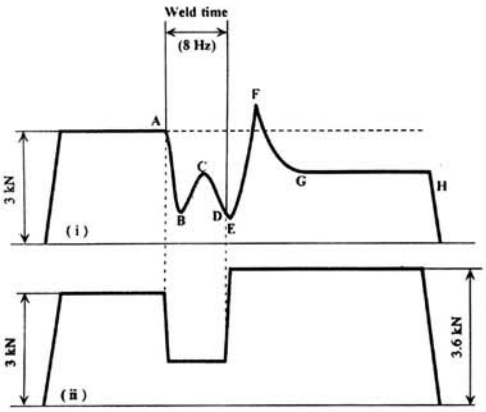
The type of the temporal change of the force in Fig.7 (b) changed to type III by increasing the welding current (type III was observed when I=8.5 and 9.0 kA in 0-100-100). The force increases as the curve BC with the elapsed time and decreases a little as the curve CD (this can be classified as type II). After that, however, the force decreases abruptly as the curve DE, increases again as the curve EF after the current-off, and decreases gradually as the curve FG with the cooling of the material. The maximum tensile shear load was 6.4 kN, nearly the same as that when I=7.5 kA.

Figure 8 (a) and (b) show the temporal changes of the force in 0-60-100 when I=6.0 and 7.5 kA, respectively. The temporal change of the force can be classified as type I. The change due to the decrease in P_1 is more clearly observed as the curve AB in Fig.8 (a) than that in 0-80-100. With the elapsed time the force increases gradually as the curve BCD due to the expansion of the material. We can see the inflection point C because the welding heat input increases due to the decrease in P_1 and the hardness of the material decreases than that in 0-80-100. The maximum force corresponding to the point E is smaller than that in 0-80-100. The maximum tensile shear load was 5.2 kN.

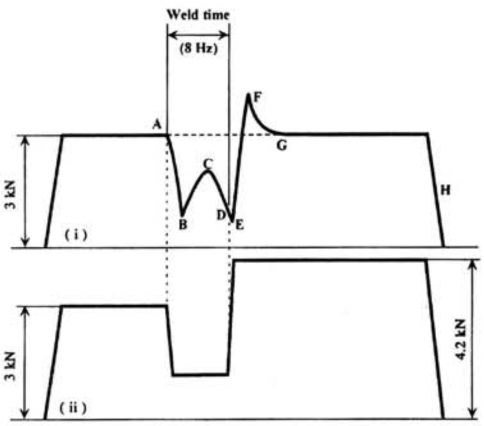
In Fig.8 (b) the similar change as that in Fig.8 (a) can be seen. The differences are that the region CD increased a little in Fig.8 (a) but kept almost the same level in Fig.8 (b), and during the shrinkage process the force is constant as the curve FG after decreasing abruptly as the curve EF in Fig.8 (b) though the force decreased gradually in Fig.8 (a). Since the general qualitative changes are the same, the change in Fig.8 (b) can be classified as type I. The change when I=8.0 kA was type III though not illustrated here.

The values of F_{max} when I=6.5, 7.0, 7.5 and 8.0 kA were 5.5, 6.2, 6.4 and 6.6 kN, which were nearly the same as those in 0-80-100.

Figure 9 (a) and (b) show the temporal changes of the force in 0-40-100 when I=6.0 and 7.5 kA, respectively. Since P_1 is very small the force decreases abruptly as the curve AB just after the



(a) 0-40-120



(b) 0-40-140

Fig. 10 Comparison of temporal change of electrode force when latter electrode force is increased (I=7.5 kA)

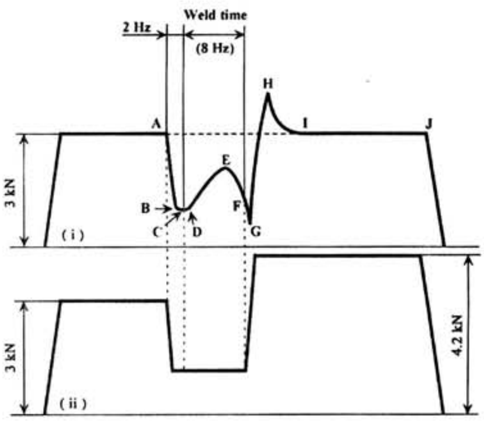
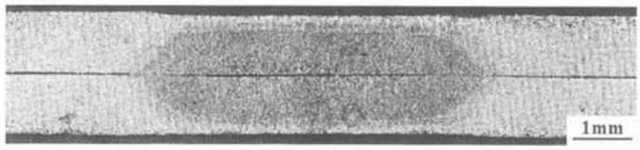
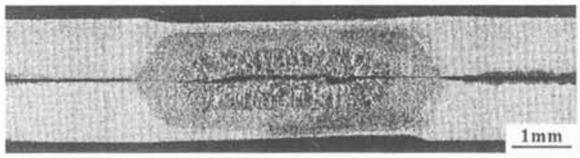


Fig. 11 Temporal change of electrode force in −2-40-140 (I=7.5 kA)

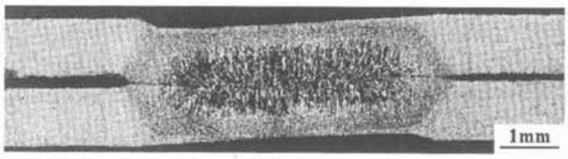
current-on. Though the force increases as the curve BC due to the expansion of the material the force at the point C is smaller than that in 0-60-100 and nearly the same as that given by the line FG in Fig.8 (b). Therefore, even if we applied the latter force P_2 =100 the force increased a little as the curve EF and after that the force in the FG region was almost the same as that in the region CD



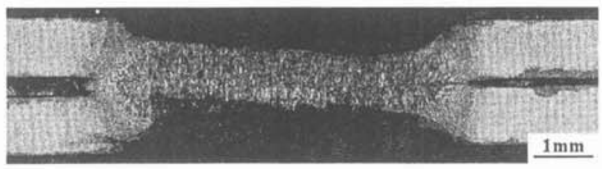
(a) I=6.0 kA



(b) I=6.5 kA



(c) I=7.0 kA



(d) I=9.0 kA

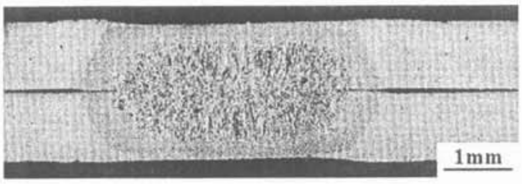
Fig. 12 Macrostructures of welds in 0-100-100

(this change was classified as type I). The value of F_{max} in this case was 5.6 kN, larger than that in 0-60-100. The values of F_{max} when I=6.5 kA was 6.0 kN, larger than that in 0-60-100, and when I=7.0 kA F_{max} was 6.3 kN, nearly the same as that in 0-60-100.

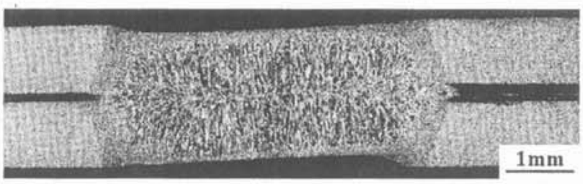
In Fig.9 (b) the weld heat input becomes larger and the deformation resistance of the material decreases in the region exceeded the point C due to the decrease in the hardness, and the force decreases abruptly as the curve CD. This tendency continues in the region DE even after the current-off. After that the force increases abruptly once and decreases gradually with the shrinkage of the material. This change was observed when the welding current was larger than 7.5 kA. This tendency was the same as that shown in Fig.6 (c) but this was observed when the welding current was larger than 8.5 kA. This means that the contact resistance increases and the weld heat input increases when the initial force decreases. The values of F_{max} when I=7.5 and 8.0 kA had larger values of 6.5 and 6.7 kN.

As mentioned above we could obtain larger values of F_{max} than others in 0-40-100. This tendency was significant when the welding current was small and we could observe the effect of decreasing the initial force.

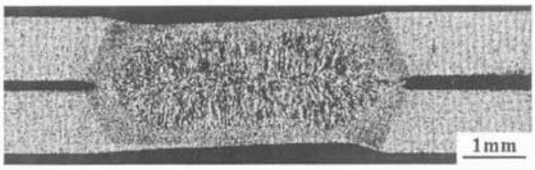
Figure 10 (a) and (b) show the results in 0-40-120 and 0-40-



(a) I=6.0 kA



(b) I=6.5 kA



(c) I=7.0 kA

Fig. 13 Macrostructures of welds in 0-40-100

140 as examples when the latter force is increased (I=7.5 kA). Qualitative change is the same as that in 0-40-100 shown in Fig.9 (b) and we can observe that the force in the region GH increases with the increase in P_2.

Figure 11 shows the result in −2-40-140 as an example when the initial force timing is changed. As is clear when we compare the result shown in Fig.11 with that in Fig.10 (b) there was no large difference between them except that the region BCD in Fig.11 was nearly horizontal. The region CD in Fig.11 corresponds the time between the current-on and the start of the expansion of the material.

4.3 Change in macrostructures of nuggets

Figure 12 (a) to (d) show macrostructures of nuggets when I=6.0, 6.5, 7.0 and 9.0 kA in the conventional process. In Fig.12 (a) the fusion zone is small and the welding is not good because we can clearly observe the weld interface. However, heat affected zone is clear. In Fig.12 (b) we can observe clearly the fusion zone. The fusion zone increases with the increase in the welding current. The heat affected zone in the thickness direction is hardly observed when I=9.0 kA. The thickness of the welds tends to decrease with the increase in the welding current and the gap between the two sheets outside of the electrode tip tends to increase.

Figure 13 (a) to (c) show macrostructures of nuggets when I=6.0, 6.5 and 7.0 kA in 0-40-100. When we compare the structure in Fig.13 (a) with that in Fig.12 (a), in which the welding current is the same, we can observe the big difference between them. That is, we can observe the clear fusion zone in Fig.13 (a) and the welding is good. This is due to the phenomenon that when the initial force decreases to 40 the weld heat input increases because the contact resistance increases.

6. Conclusions

(1) In the conventional process the electrode force changed complexly with the elapsed time and the changes were divided into three types depending on the welding current.

(2) When we decreased the initial electrode force than that in the conventional process good welds could be obtained even in the lower welding current and the decrease in the thickness of the welds could be lowered.

(3) When we decrease the initial electrode force the temporal changes of the electrode force could be explained during the expansion and shrinkage of the welds, though the electrode force changed complexly depending on the initial electrode force and the welding current.

Acknowledgement

The authors would like their sincere gratitude to Mr. Satoshi Tagawa who graduated from Kyushu Institute of Technology for his kind cooperation in this study.

References

1) Editorial Board of New Engineering Review of Joining, New Engineering Review of Joining, Intech Information S.C. Ltd. (1994), p.290 (*in Japanese*)

2) For example, Japan Welding Society, Handbook of Welding and Joining, Maruzen (2003), p.352 (*in Japanese*); T.Nakamura, T.Kobayashi, H.Morimoto, Outline of Modern Welding Technique, Vol.8, Resistance Welding, Sanpo-shuppan, (1975), p.1 (*in Japanese*); M.Hamazaki, Outline of Modern Welding Technique, Vol.32, Easy Resistance Welding, Sanpo-shuppan, (1975), p.1 (*in Japanese*)

[溶接学会論文集 第24巻 第1号 p. 10-16 (2006)]

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.

*Recieved: 2005. 5. 19

**Member, Aichisangyo Co. Ltd.
***Member, Kyushu Institute of Technology

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

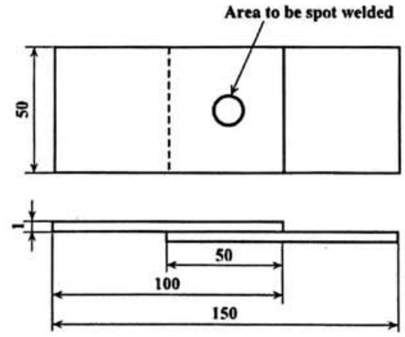


Fig. 1 Shape and dimensions of a specimen for spot welding