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Influence of Welding Parameters on the Tensile Shear Strength of Aluminum Alloy Joint Welded by Resistance Spot Welding

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Aluminum alloy A5052 sheets were welded using the technique of resistance spot welding with cover plates. The effects of welding parameters on the tensile shear strength of the joints were investigated. The results reveal that the technique is feasible to weld aluminum alloy, and that the enhanced electrode force is more effective than the extended down-sloping time for inhibiting pores formation and increasing the strength of the joint.

Keywords aluminum alloy, resistance spot welding, tensile shear strength, welding parameters

1. Introduction

In automotive industries, weight reduction is strongly demanded for energy and natural resource savings. Owing to high specific strength, low density, high corrosion resistance, and low-energy formability, aluminum alloys have been adopted and are expected to be extensively used in the future, to replace steel as the primary material of construction in automobile. Resistance spot welding is the major joining process in automotive body construction because of its low cost, easy automation, minimum skill requirements, and robust to part tolerance variations. Consequently, resistance spot welding of aluminum alloy sheet is of significant interest for the automotive manufacturing process.

However, there are two major problems with resistance spot welding of aluminum alloy. First, short electrode tip life. The surface of aluminum alloy sheet is covered with high electrical resistance, non-uniform oxide layer. When the electrodes squeeze the sheets before supplying current, the electrode crush the oxide layer non-uniformly, allowing small areas for current conduction. The high welding current density on the small area causes excessive heating, local melting, and alloying of copper and aluminum, which results in severe electrode wear (Ref 1-4). The tensile strength of the joint varies due to the electrode tip instability over the useful electrode life (Ref 1). Second, enormously high welding current is required. Since aluminum has higher electrical and thermal conductivities than steel, high electric currents have to be used in welding aluminum alloys (Ref 5-7). However, this is contrary to initial desire of energy saving by using aluminum alloy.

Qiu et al. have already developed and reported the technology of resistance spot welding with cover plate, which has been used to weld magnesium alloy sheets, aluminum alloy-to-steel in the previous studies (Ref 8, 9). The preceding investigations reveal that the strong joints can be obtained under relatively low welding current condition using the method of resistance spot welding with cover plate, and that the electrodes do not contact with aluminum alloy or magnesium alloy sheets which would be helpful for increasing electrode life.

In the present study, aluminum alloy sheets were welded using this method. The effects of welding parameters on the tensile shear strength of the joint were investigated to obtain better understanding of the resistance spot weldability of aluminum alloy and provide some foundational information for improving mechanical properties of the aluminum alloy joints.

2. Experimental Materials and Procedure

Aluminum alloy A5052 sheet with thickness of 1.0 mm was used in this study. Table 1 shows its compositions. Spot welding was carried out by a stationary resistance spot welding machine. Figure 1(a) and (b) shows the shape of specimens and the schematic diagram of the process, respectively. The aluminum alloy sheets were placed between both cover plates of steel in the welding process. Further details concerning the procedure of resistance spot welding with cover plate have been reported by Qiu et al., who have investigated the resistance spot welding of magnesium alloy AZ31B (Ref 8). Welding conditions are shown in Table 2.

In order to examine the mechanical properties of the joints, the tensile shear test was performed under a cross-head speed of 1.7×10^{-5} m s^{-1} at room temperature. The nugget diameter was measured from the fractured surface after tensile shear testing. The joint tensile shear load and nugget diameter were determined, based on the average value over five measurements per condition.

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Table 1 **Chemical composition of materials (mass%)**

Element	Mg	Fe	Cr	Si	Mn	Cu	Zn	Al
Per centum	2.2	0.27	0.19	0.09	0.049	0.027	0.005	Bal.

Table 2 **Welding conditions**

	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7
Welding current, kA	5-12	10	10	10	10	6	6
Welding time, cycle	10	5-25	10	10	10	10	10
Electrode force, kN	2	2	1-6	2	1-6	1-6	2
Down-slope time, cycle	0	0	0	0-30	0	0	0-30
Pre-treatment	Degreasing with acetone						
Electrode tip	Cu-Cr alloy; conical electrode tip (ø6)						

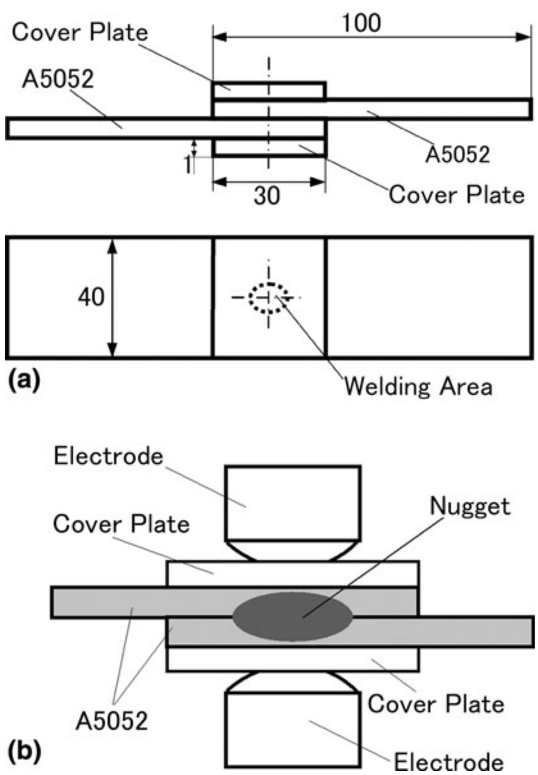

Fig. 1 Configuration and dimension of specimen (a) and schematic diagram of spot welding with cover plates (b)

Also investigated were weld joints produced by resistance spot welding without the use of cover plates for comparison of the two methods.

3. Experimental Results and Discussions

Figure 2 shows the effects of welding current on the tensile shear load and nugget diameter of the joints welded under the welding conditions of set 1. The nugget diameter and tensile shear load of the joints increased with the increasing of the welding current. The maximum tensile shear load of 5.5 kN and nugget of 9.32 mm in diameter were obtained at welding current of 12 kA. Moreover, the fracture type of the joints varied depending on the welding current. Shear and plug fracture were observed in the range of 5-6 kA and 7-12 kA of the welding current, respectively.

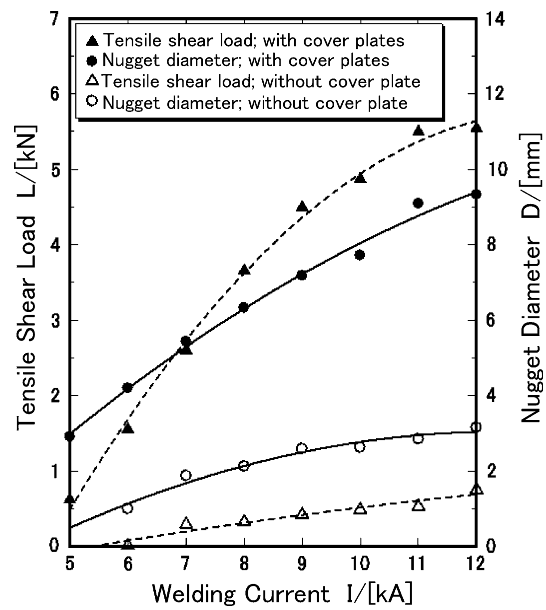

Fig. 2 Effects of welding current on tensile shear load and nugget diameter

It should be noticed that the joints welded by conventional resistance spot welding without use of cover plate exhibited lower strength and smaller nugget under the same welding conditions in comparison with the joints welded by the resistance spot welding with cover plates, even the welding was unattainable by conventional resistance spot welding when welding current below 6 kA. This is attributed to the effect of the cover plates on the formation of nugget.

Figure 3 shows the effects of welding time on the nugget diameter and tensile shear load of the joints welded under the welding conditions of set 2. The nugget diameter and tensile shear load of the joints increased with the increasing of the welding time. However, with the variation of welding time from 5 to 25 cycles, the tensile shear load and nugget diameter of joints varied only from 4 to 5.5 kN and from 6.7 to 8.9 mm, respectively. In comparison with their welding current dependence, extending the welding time was not as effective as increasing the nugget diameter and tensile shear strength of joint. This is considered to be due to high electrical and thermal conductivity of aluminum alloy. These inherent properties caused the heat runaway via aluminum alloy sheet increased rapidly with the increasing of time. The results also suggested that a larger weld nugget is difficult to obtain by extending the welding time. Moreover, the fracture type of joints was plug type fracture through all welding time in such a case.

In resistance spot welding, heat input increases with the increase of weld current and/or time, resulting in an increase in nugget diameter. The tensile shear load of joints increased with the increasing of the welding current and time as shown in Fig. 2 and 3. It is owed to the increasing of the nugget diameter, which is a major influence factor for joint strength in both cases of shear fracture and plug fracture (Ref 10).

Figure 4 shows the effects of electrode force on the nugget diameter and tensile shear load of joints welded under the welding conditions of set 3. The nugget diameter and tensile shear load of the joints decrease with the increasing of the electrode force. This is considered to be caused by the following two factors. First, superior sheet separation, which was caused by higher electrode force, suppressed the nugget growth. Second, the decrease in the energy density of the welding region, which resulted from the initial contact resistance between sheet-sheet decline and the radiation via electrodes increase because the initial sheet-sheet, electrodes-sheets contact area increased with the increasing of the electrode force (Ref 11). For the fracture mode of the joints, the fracture type of joints was plug fracture through all electrode force.

Imamura et al. welded 1.01-mm thickness Al-4.5Mg alloy sheets using resistance spot welding, and obtained the maximum tensile shear load of 3.5 kN and nugget diameter of 5 mm from joints welded under the condition of welding current of 25 kA (Ref 4). Compared to their result, the joints welded by resistance spot welding with cover plates exhibited higher tensile shear load and larger nugget. This is attributed to the effect of the cover plates on the formation of nugget. That is, large heat generated in cover plates due to their low electrical conductivity, transferred to the welded region in the aluminum alloy, enhanced heat of welded region, and resulted in the formation of larger nugget. This suggested that the technique of resistance spot welding with cover plates enabled aluminum alloy welding under the same welding condition of low welding current as that of the resistance spot welding of steel.

The formation of pores is a common phenomenon in the resistance spot welding of aluminum alloy, which is related to the occurrence of shrinkage strain and expulsion (Ref 5, 8, 12). Since the expansion of molten aluminum alloy metal is constrained by the surrounding solid metal during the heating process in resistance spot welding, the shrinkage strain occurs and causes insufficient aluminum in the molten weld cavity. As well known, post-heating after welding can alleviate shrinkage strain during welding. In resistance spot welding process, down-sloping time generally is used to control the cooling rates of weld. Figure 5(a) presents cross-section of several joints welded under the welding conditions of set 4 as shown in

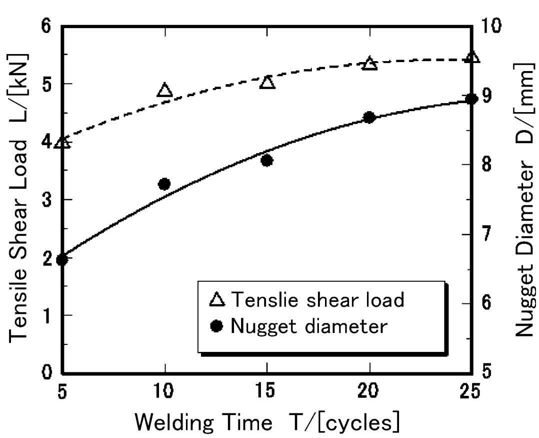

Fig. 3 Effects of welding time on tensile shear load and nugget diameter

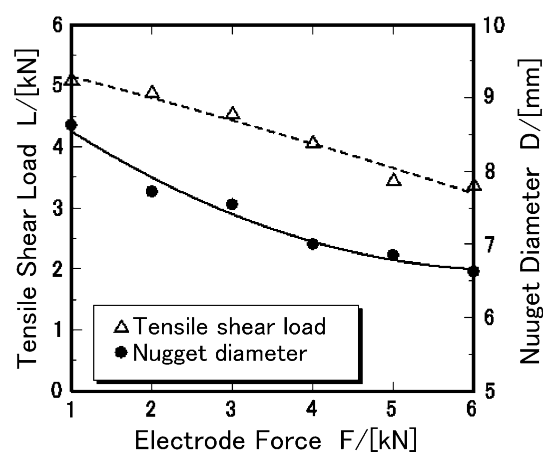

Fig. 4 Effects of electrode force on tensile shear load and nugget diameter

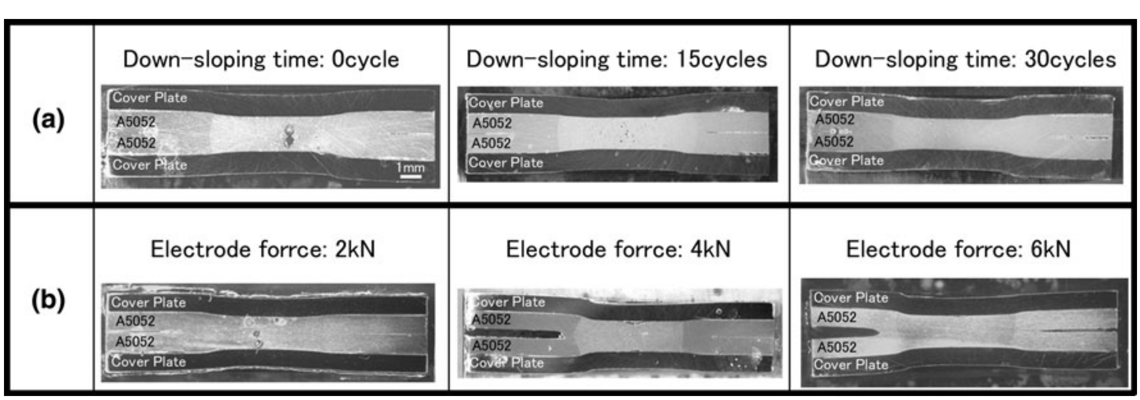

Fig. 5 Cross-section of joints welded under various down-sloping time and electrode force

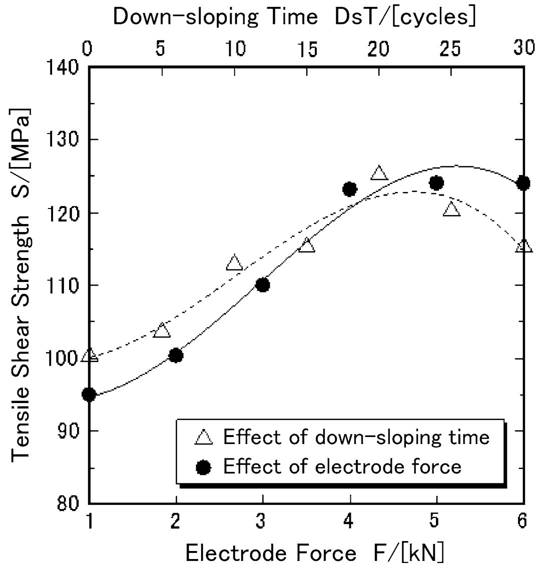

Fig. 6 Effects of electrode force and down-sloping time on tensile shear strength

Table 2. It can be seen from these pictures that the pores reduced with the increasing of down-sloping time. On the other hand, the expulsion happens when the force from the nugget exceeds the force from the electrodes (Ref 12). Consequently, enhanced electrode force can effectively reduce the expulsion happens. Figure 5(b) shows the cross-section of several joints, which were welded under different electrode force under the welding conditions of set 5. As shown, the pores also reduced with the increasing of electrode force. This is because the expulsion occurrence was suppressed by the action of higher electrode force. The results described above indicated that the pores formation can be suppressed by applying long down-sloping time or high electrode force.

In the previous study (Ref 8), it has been concluded that the tensile shear strength of joint is unaffected in the case of plug fracture and effected in the case of shear fracture. Figure 6 shows the effects of electrode force and down-sloping time on the tensile shear strength of the joint welded, respectively, under the welding conditions of set 6 and 7, in which the tensile shear strength of the joints were calculated by fracture surface area and tensile shear load of the joint when it was shear fracture. As shown, the strength of joint increased with the increasing of electrode force, while the strength increased to the down-sloping time of 20 cycles and then decreased after the down-sloping time of 20 cycles with the increasing of down-sloping time. The former is considered to be due to the pores reduction with the increasing of electrode force as shown in Fig. 5. The latter is attributed to the combinational effects of the pores and crystal grains in the nugget. That is, the influence of pores reduction were major when down-sloping time shorter than 20 cycles, whereas the influence of pores reduction was shadowed by one of the grain coarsening which caused from long down-sloping time when down-sloping time longer than 20 cycles. Therefore, the enhanced electrode force was more effective than the extended down-sloping time for reducing pores formation and increasing the strength of the joint.

4. Conclusions

In this study, aluminum alloy sheets were welded using the method of resistance spot welding with cover plates. The effects of welding parameters on the tensile shear strength of joint and the pores formation were investigated. The results reveal that the resistance spot welding with cover plate is feasible to weld aluminum alloy, and that the enhanced electrode force is more effective than the extended down-sloping time for inhibiting pores formation and increasing the strength of the joint.

Acknowledgments

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