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Temperature Measurement During Friction Stir Welding of Dissimilar Aluminum Alloys

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Friction stir welding (FSW) has been applied to joints of dissimilar aluminum alloys, different two alloys, ADC12 and A6061 arranged in Advancing side (AS) and A1050 arranged in Retreating side (RS). Temperature during FSW was measured in different offset of 0.00mm, 0.25mm, 0.50mm and 1.00mm, which was the distance from the butt plane to the center of the tool, in order to discuss the relation between FSW result and temperatures in both sides.

FSW was applied successfully to a joint of [AS] A6061Al/ [RS] A1050Al with good joint surface in all offsets. The temperature measurement showed that the heat input increased with increase of the offset. The temperature at the butt plane during FSW with an offset of 1.00mm raised up to the solution treatment temperature of A6061Al, that is, 515°C - 550°C. Then, the flow stress of the alloy likely lowered during FSW owing to not only high temperature but also resolution of the precipitates. The temperatures in Rank 1 of [AS] ADC12/ [RS] A1050Al were higher than those of [AS]A6061 in various offsets as a whole. Especially, the temperature at 4mm of AS was high compared with that at Center 1 and rose with increase of the offset.

Keywords: *friction stir welding, offset, temperature, dissimilar alloys*

1. Introduction

The friction stir welding (FSW) is a joining technology in solid state for aluminum base alloys in which fusion welding is not always easy. Application of the friction stir welding to dissimilar aluminum alloys is not only industrially but also academically interesting and important [1-3]. It is known that the temperature in FSW depends on materials joined, and is likely related to the success or failure of the welding.

The aim in the present study is to investigate the temperature variation in FSW for dissimilar aluminum alloys of A6061 or ADC12 in advancing side (AS) and A1050 in retreating side. Then, the relation between temperature and joining status was discussed to find optimum condition for welding.

2. Experimental methodology

2.1 Chemical composition and mechanical properties of sample

The chemical compositions and mechanical properties of sample are shown in Tables 1 and 2.

Table 1 Chemical compositions of aluminum alloys used [mass%]

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ni	Ti	Sn	Al
A1050	~0.25	~0.40	~0.05	-	~0.05	-	~0.05	-	~0.03	-	Bal
A6061	0.40~0.80	~0.70	0.15~0.40	~0.15	0.8~1.2	0.04~0.35	~0.25	-	~0.15	-	Bal
ADC12	9.6~12.0	~1.3	1.5~3.5	~0.5	~0.3	-	~1.0	~0.5	-	~0.3	Bal

Table 2 Mechanical property of aluminum alloys used

Alloy	Tensile strength (MPa)	0.2%Proof strength (MPa)	Elongation (%)	Melting point (°C)	Thermal conductivity (W/m･°C)
A1050	110	105	10	657	231
A6061	310	275	12	652	167
ADC12	295	185	2	580	92

2.2 Experimental procedure

The FSW parameters and the tool parameters are listed in Tables 3 and 4, respectively. The tool shape is shown in Fig. 1. The left hand thread was cut in the probe of the tool, and the direction of the tool rotation was clockwise.

Table 3 FSW parameters used in the present study

Tool angular advance	3°
Tool depth	1.7mm
Tool rotation speed	1460rpm
Tool traveling speed	200-350mm/min

Table 4 Tool parameters

Material of tool	SKD61
Diameter of shoulder, d_1	8mm
Diameter of probe, d_2	3mm
Length of probe, h	1.7mm

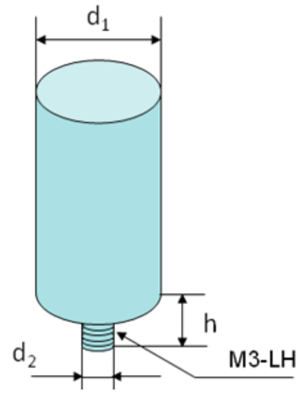
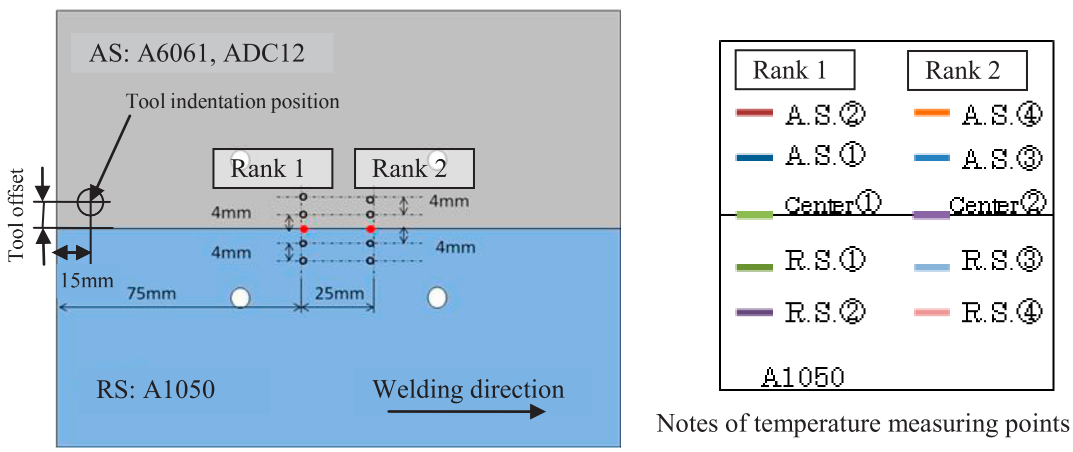


Fig. 1 Tool shape

Figure 2 illustrates the arrangement of the weld sheets and thermo-couples with inserting positions and dimensions. Figure 3 shows the side view in welding direction of the arrangement of the thermo-couples in an offset of 0.00mm. Because the primary aim of the experiment was a temperature survey in the material during FSW, the temperatures at ten points were measured by one trial in the arrangement shown in Figs. 2 and 3. To control heat input distributed to advancing and retreating sides, a tool offset was set as a FSW parameter. The tool offset is defined as the distance between the tool center and butt line of weld sheets toward advancing side (AS). The offset was employed to be four kinds of values, 0.00, 0.25, 0.50 and 1.00mm.



Sheet size: 185mmL×80mmW×2mmT

Fig. 2 Arrangement of the weld sheets and thermo-couples with inserting positions and dimensions.

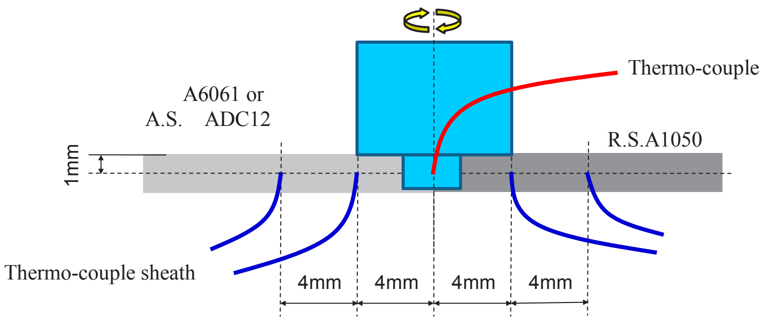


Fig. 3 Side view in welding direction of the arrangement of the thermo-couples in an offset of 0.00mm

2.3 Sampling time

A sampling time related to the temperature measurement accuracy was an important factor. The different sampling times were used in two joints because it had seemed that the temperature rise at the sampling time was somewhat large at a sampling time of 100ms in the experiment of [AS]A6061/ [RS]A1050. The sampling time of 10ms was selected in [AS]A6061/ [RS]A1050 in consideration of sufficient accracy and ease of dealing data. Supposing the tool traveling speed is 200mm/min, 3.3mm/s corresponds 0.33mm for a sampling time of 100ms and 0.033mm for 10ms.

3. Experimental results and discussion

An example of change in temperature during FSW of AS ADC12/ RS A1050 with a offset of 1.00mm is shown in Fig. 4. The temperature at Center 1 (Figure 4(a)) begins to rise up at about 66s and increases exponentally up to 361°C at 73.44s. The time 73.44 is supposed to be one for failure of the thermocouple used. As shown in Figure 5(a), the temperatures in Rank 1 are higher than those in Rank 2. The temperature in AS is higher than that in RS, because of not only general reason but also the offset of tool toward AS.

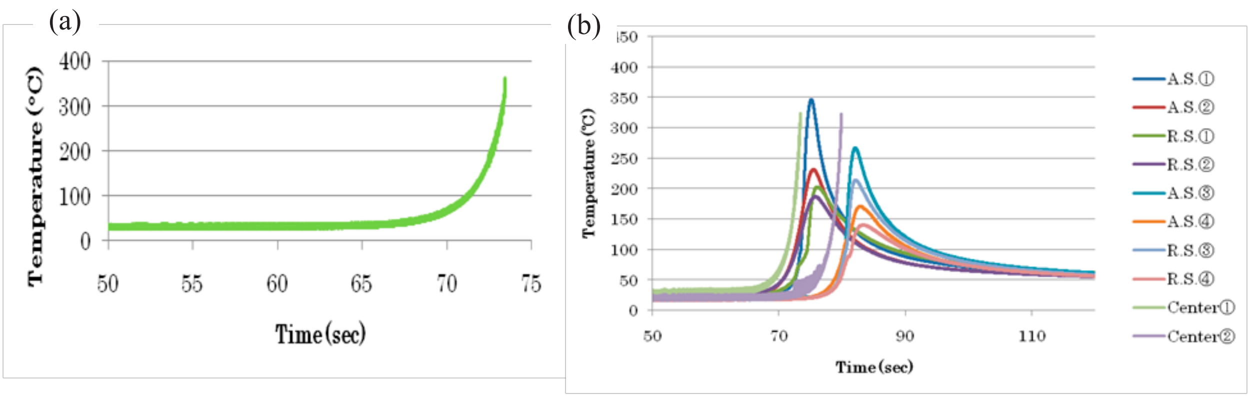


Fig. 4 Change in temperatures during FSW of AS ADC12/ RS A1050 with an offset of 1.00mm: at (a) Center 1 and (b) each 5 points in Rank 1and 2, which were sited in both sides of butt line.

The maximum temperatures at each point during FSW of [AS]A6061/ [RS]A1050 and [AS]ADC12/ [RS]A1050 are shown in Fig. 5. The temperatures were displayed for Rank 1 and 2 of thermo-couples.

The common tendency found from the experimental results of [AS]A6061/ [RS]A1050 and [AS]ADC12/ [RS]A1050 is as follows. The heat input in FSW is larger when the offset of tool is larger. This is probably related to contact areas of alloys given friction by rotating tool. In the present study, as the harder alloy, A6061 or ADC12 was arranged in AS, the larger offset to AS means the larger contact area between the tool and the harder alloy, which leads to the higher vertical force or frictional force and the higher frictional heat. The temperature at each point depends on the distance from the tool as heat source. Therefore, the heat input by frictional heat increased, and it became a high temperature.

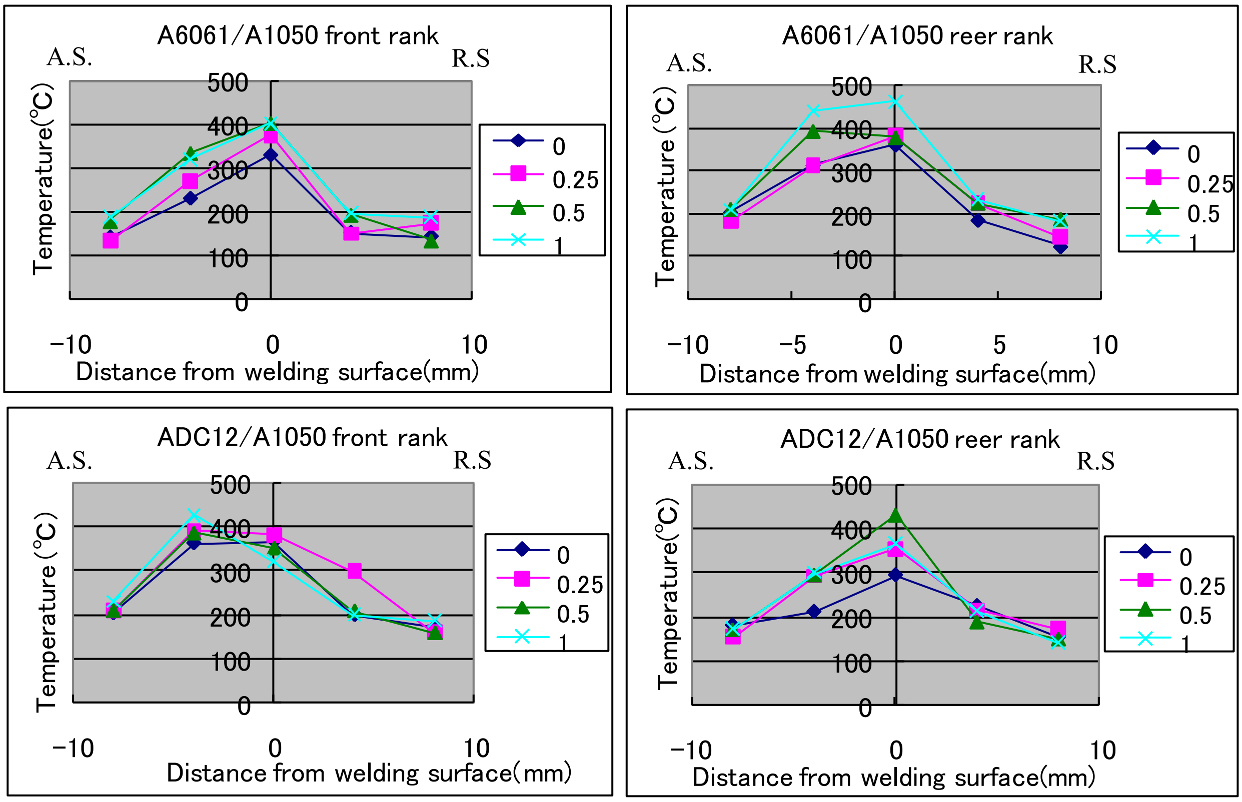


Fig. 5 Maximum temperature at each point during FSW of [AS]A6061/ [RS]A1050 and [AS]ADC12/ [RS]A1050.

Some important differences in temperature distribution between [AS]A6061/ [RS]A1050 and [AS]ADC12/ [RS]A1050 were found. The temperatures in Rank 1 of [AS]ADC12 were higher than those of [AS]A6061 in various offsets as a whole. Especially, the temperature at 4mm of AS was high compared with that at Center 1 and rose with increase of the offset. The positions of 4mm in both As and RS correspond to the edge of tool shoulder. Thus, the high temperature at 4mm of AS implies that the edge of tool shoulder, which has the highest tangentical speed principally, is an extremely important source of heat. On the other hand, the temperatures in Rank 2 of [AS]A6061 were higher than those of [AS]ADC12 in various offsets as a whole. Essentially the temperature in Rank 2 is spposed to be higher than that in Rank 1 because the pre-heating time for Rank 2 was longer than that for Rank 1. It is, therefore, understandable that the temperatures in Rank 2 of [AS]A6061 is higher than that in Rank 1. However, the lower temperatures in Rank 2 of [AS]ADC12 than that in Rank 1 suggested a unexpected cause. A possible cause is that the higher resistance in the latter stage of FSW is generated owing to a low temperature of a forward material with a low thermal conductivity of 92W/m·°C for ADC12, and then the tool rises up slightly.

As to a bead feature of FSW, [AS]A6061/ [RS]A1050 joint was more smooth than [AS]ADC12/ [RS] A1050 one. The bead feature of [AS]ADC12/ [RS] A1050 was not changed with increase of the offset, while that of [AS]A6061/[RS]A1050 was somewhat improved. Such difference can be understood based on temperature dependence of mechanical properties of the alloys. Figure 6 presents changes in mechanical properties against temperature in A6061, ADC12 and A1100 [4] instead of A1050. The elongation and tensile strength increase as the temperature rises. However, while the properties of A6061 indicate values close to those of A1100 at a relatively low temperature, the elongation is fairly small and the tensile strength is higher in ADC12 at high temperatures. Such differences in mechnical properties at high temperatures, that is, during FSW likely resulted in the rough feature of the bead.

Relation between FSW of [AS]A6061/ [RS]A1050 and the temperature is explained as follows.

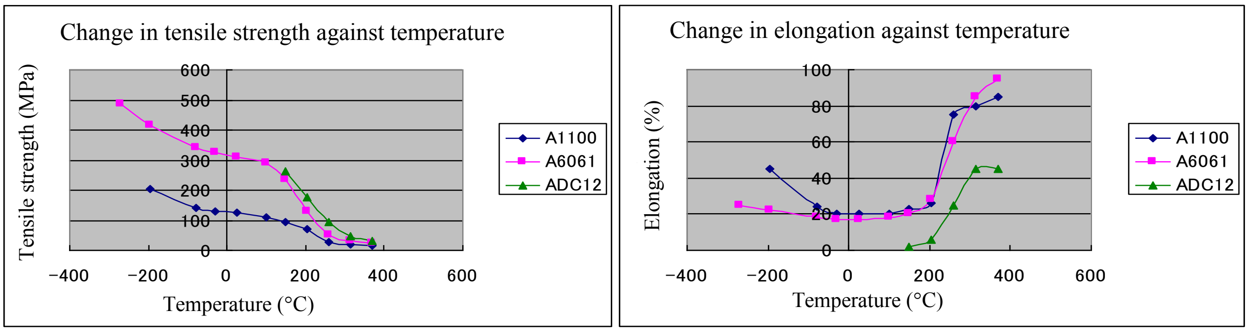


Fig. 6 Mechanical properties of alloys as a function of temperature [4].

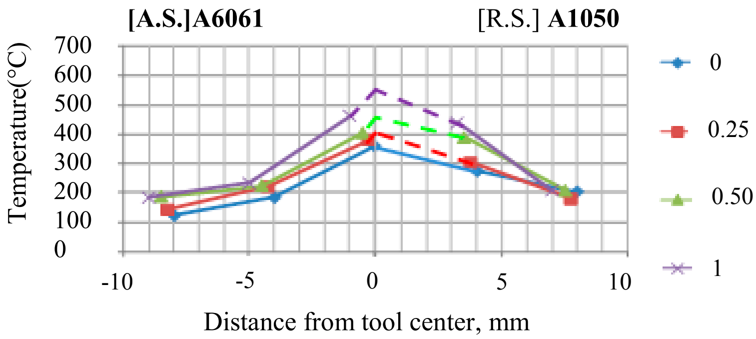


Fig. 7 The temperature distribution against the distance from the tool center.

As mentioned above, the position of the tool or the maximum temperature was changed to the measuring points of temperatures with the value of the offset. The temperature distribution against the distance from the tool center is displayed in Fig. 7. As shown in the figure, a temperature of the tool center in a offset of 1.00mm will rise up to about 550°C if a temperature of the tool center rises according to the dash line. The temperature of 550°C is correspondent to the temperature range of the solution treatment, 515 to 550°C for A6061. Therefore, at the high temperature precipitats of Mg_2Si resolved, the difference in strength between A6061 and A1050 became small and the two alloys could be stirred well. Moreover, it can be understood that the increase in the offset is one of factors for raising up the heat input as the temperature at a position -1mm from the tool center is estimated as 316, 352, 382 and 462°C for the offset of 0.00, 0.25, 0.50 and 1.00mm, respectively.

4. Conclusions

In the present study, the temperature variation in FSW for dissimilar aluminum alloys of A6061 or ADC12 in advancing side (AS) and A1050 in retreating side has been investigated to find optimum condition for welding. The results obtained are as follows:

The common tendencies in both of [AS]A6061/ [RS]A1050 and [AS]ADC12/ [RS]A1050 are found.
(1) The heat input in FSW is larger when the offset of tool is larger.
(2) The temperature at each point depends on the distance from the tool as heat source.

Some important differences in temperature distribution between [AS]A6061/ [RS]A1050 and [AS]ADC12/ [RS]A1050 were found.
(3) The temperatures in Rank 1 of [AS]ADC12 were higher than those of [AS]A6061 in various offsets as a whole. Especially, the temperature at 4mm of AS was high compared with that at Center 1 and rose with increase of the offset.
(4) The temperatures in Rank 2 of [AS]A6061 were higher than those of [AS]ADC12 in various offsets as a whole.
(5) The bead feature of [AS]A6061/ [RS]A1050 joint was more smooth than [AS]ADC12/ [RS] A1050 one.

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