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Joining of 5083 and 6061 aluminum alloys by friction stir welding

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Friction stir welding (FSW) has emerged as a new solid state joining technique [1], especially for aluminum alloys [2–6]. In this process, a rotating tool travels down the length of contacting metal plates, and produces a highly plastically deformed zone through the associated stirring action. The localized heating zone is produced by friction between the tool shoulder and the plate top surface, as well as plastic deformation of the material in contact with the tool [1].

At the present time, FSW is used mainly for joining similar materials. For dissimilar welding, there have been few systematic studies aimed at clarifying the effect of material combination and welding conditions on weld properties [7, 8].

However, FSW of dissimilar materials will be required in the near future for advanced aircraft design. In the present research, we have tried to apply the FSW technique to dissimilar light metals such as 5083 and 6061 aluminum alloys. Then, we have examined the microstructure and the mechanical properties of the FSWed aluminum alloy joint.

3 mm thick plates of cold-rolled 5083 (0.4%Si, 0.4%Fe, 0.4%Mn, 4%Mg, balance Al) and 6061-T6 (0.7%Si, 0.7%Fe, 0.1%Mn, 1.0%Mg, 0.4%Cu, 0.1%Cr, balance Al) aluminum alloys were used in this experiment.

Fig. 1 shows a schematic illustration of the experimental apparatus. The test piece was fixed onto a steel plate horizontally. Welding direction was perpendicular to the rolled direction of the aluminum plates. The diameter of the tool shoulder was 10 mm. The diameter of the insert pin and height were 3.0 mm and 2.8 mm respectively. The tool rotation speeds were 890 rpm and 1540 rpm. The traverse speeds of the moving table were 118 mm/min and 155 mm/min.

Fig. 2 shows combinations of test pieces. Following FSW, microstructures of the samples were observed by optical microscopy. Vickers microhardness profiles were measured on the cross section perpendicular to the welding direction. Tensile tests were performed to evaluate the mechanical properties. Fig. 3 shows dimensions of a tensile specimen. Variations of the Vickers hardness by aging were also evaluated.

Fig. 4 shows the typical appearance of a welded 5083-6061 specimen. Both at the top and at the root surfaces, surface roughness, i.e., surface quality, was excellent. Waving burrs on the top surface were observed on the retreating side.

Fig. 5a and b show the optical micrographs of the cross sections. In Fig. 5c, the lines indicated by A-A′ and B-B′ show the position corresponding to the photographs of cross section shown in Fig. 5a and b, respectively. Since 5083 and 6061 aluminum alloys have different etching behaviors, the metal flow from two sides was clearly visible in the nugget (friction stirred region). On the upper side, the two aluminum alloys are clearly separate. In contrast, a complicated layer structure, which consists of the two aluminum alloys, was observed on the lower part. The structure was formed by the traverse of the rotating tool and the thread of the insert pin.

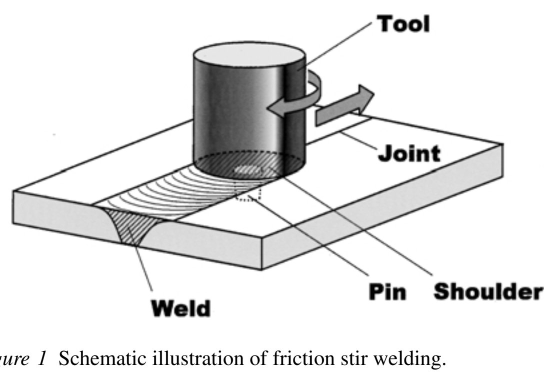
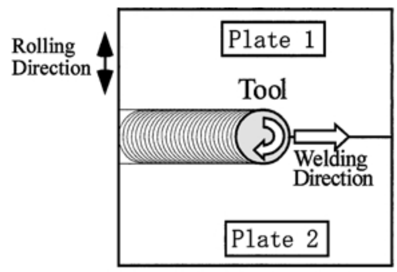


Figure 1 Schematic illustration of friction stir welding.



No	Plate 1	Plate 2
No. 1	5083	5083
No. 2	6061	6061
No. 3	6061	5083

Figure 2 Combinations of joining materials.

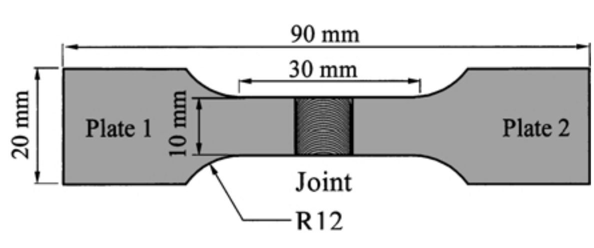


Figure 3 Dimensions of test piece for tensile test.

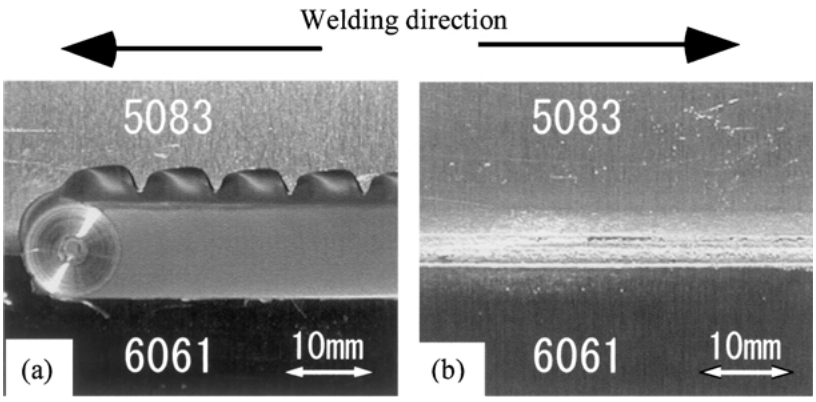


Figure 4 Typical appearance of 5083 and 6061 aluminum alloy joint. (a) Top surface (b) root surface.

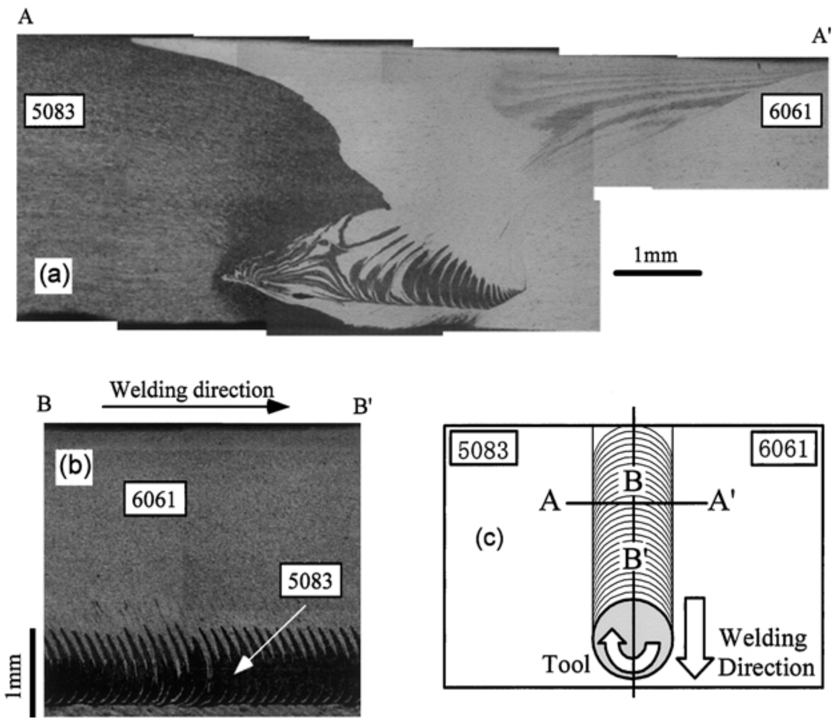


Figure 5 Cross sections of 5083 and 6061 aluminum alloy joint. (a) Cross section perpendicular to the welding direction (line indicated by A-A′ in (c)). (b) Cross section parallel to the welding direction (line indicated by B-B′ in (c)).

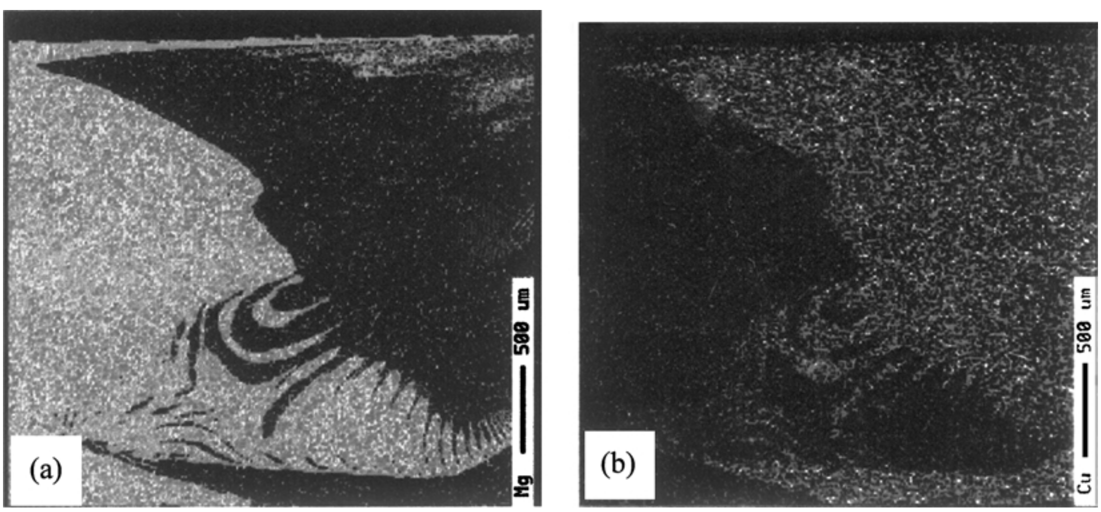


Figure 6 Element distribution map on the cross section of 5083-6061 joint specimens by EPMA. (a) Mg and (b) Cu.

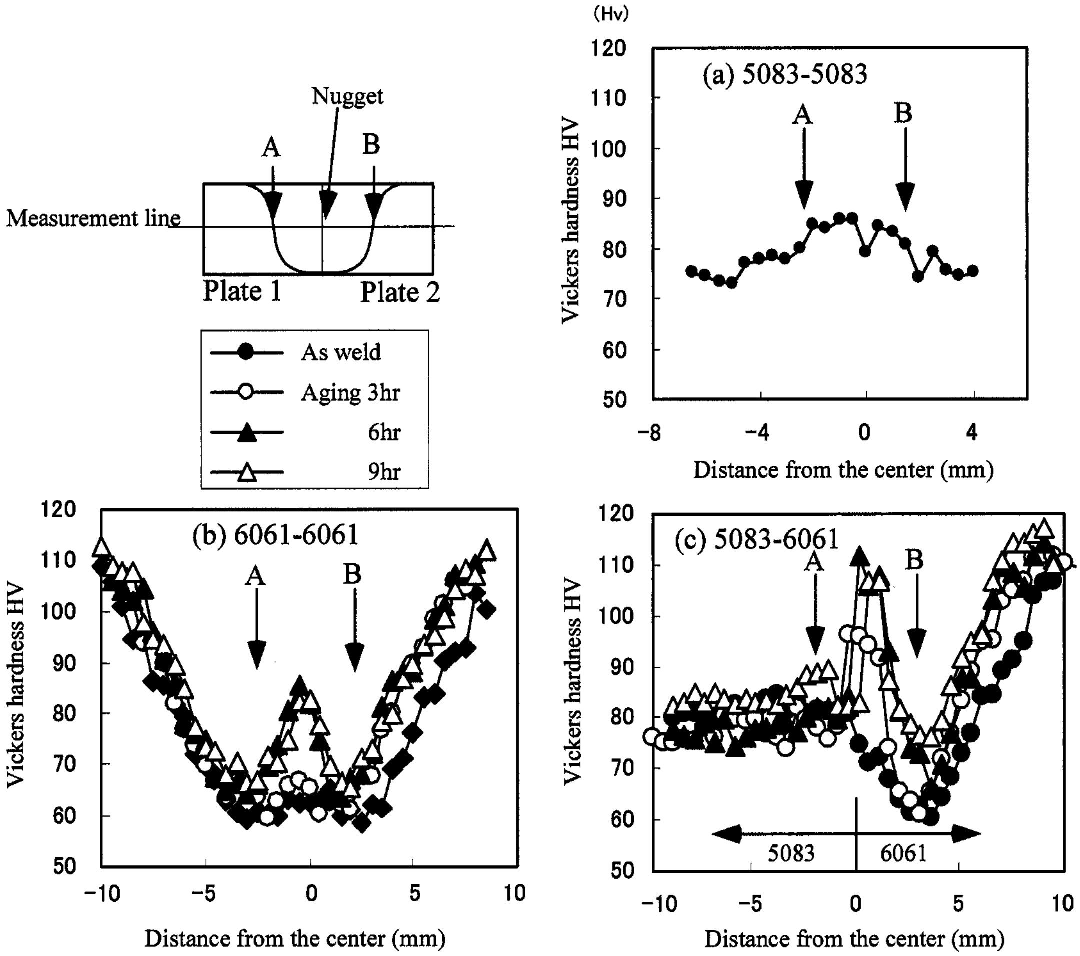


Figure 7 Vickers hardness distribution of as-welded and after aging materials (at 433 K in oil bath) in cross section perpendicular to the welding direction. (a) 5083-5083 joint (b) 6061-6061 joint and (c) 5083-6061 joint.

Fig. 6 shows element distribution maps by EPMA. Mg-rich regions and Cu-rich regions corresponded to 5038 and 6061 aluminum alloys, respectively. It seems that diffusion and chemical reaction did not occur. But, if the temperature during FSW was increased, element diffusion would be accelerated.

Fig. 7 shows the hardness distribution at various cross sections of the specimens. At the 5083-5083 joining zone, the hardness was slightly higher than the original value because of grain refinement. However, in the 6061-6061 joining zone, the hardness dropped sharply. The hardness depends on the precipitate distribution such as Mg_2Si. It is likely that the low hardness can be attributed to the re-solution of the precipitates during FSW. Effects of aging on the hardness distributions are also shown in Fig. 7. The aging temperature was 433 K. Black dots show the hardness distribution as welded. White dots, black triangles and white triangles show hardness distributions after aging for 3 h, 6 h and 9 h respectively. The hardness at the interface of the joints increased as the aging time increased. However, outside the nugget, hardness recovery did not occur. The temperature outside was lower than that in the nugget. It seems that the dissolution of precipitates rarely occurred in the heat-affected zone during FSW and that grain growth of precipitates have influence on hardness.

Table I shows the results of tensile tests. The strength of the 5083-5083 joint was 97% of that of the original material. In contrast, the strength of the 6061-6061 joint was 63% of that of the original material. The strength of the 5083-6061 joint was almost equal to that of the 6061-6061 joint. These results show that the tensile strength of the joint is affected by the type of joint (similar or dissimilar) and the alloys (5083 or 6061).

FSW of the similar materials (5083 and 6061 aluminum alloys) and dissimilar materials (6061/5083) was carried out. Every combination of materials was joined successfully. Thus FSW has the potential for joining dissimilar materials such as different types of aluminum alloys. Welding properties, such as the hardness distribution and the tensile strength, were strongly influenced by the material combination.

TABLE I Tensile strength and elongation of mother material and joint specimens

	Strength (MPa)	Elongation (%)
Alloy		
5083	328 ± 2	24 ± 1
6061	320 ± 2	16 ± 1
Joint		
5083-5083	318 ± 2	21 ± 3
6061-6061	199 ± 6	11 ± 1
6061-5083	202 ± 3	7 ± 1

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