Friction Stir Welding of 6061 Metal-Matrix Composite†

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Fusion welding of aluminum metal-matrix composites (MMC) with ceramic particle reinforcement is difficult due to the irregular redistribution of reinforcement particles, and the reaction between reinforcement particles and matrix aluminum as well as weld defects such as porosity in the fusion zone[1].

Among solid state joining processes, Friction Stir Welding, (FSW), is a unique process for producing continuous butt-welded joints similar to those made by fusion welding[2]. FSW is mainly used for welding aluminum alloys, but other materials such as copper alloys, magnesium alloys, titanium alloys and even steels can be welded by FSW as well as MMC[3, 4].

In this paper, the applicability of FSW to welding aluminum metal-matrix composites with ceramic particle reinforcement has been examined. Material used was 6061 metal-matrix composite reinforced with 10 volume percent Al_2O_3 particles, made by Duralcan. The composition of 6061 is shown in **Table 1**. 6061-MMC ingot was forged to plate and heat-treated by the T6 condition (solution heat treatment : 808Kx1h, aging treatment : 448Kx8h). Specimens for FSW was 50 mm wide, 100 mm long and 4 mm thick plate. Square butt joint was selected. Groove surface was machined and degreased by acetone. As FSW conditions, tool rotation speed and welding speed were varied in the ranges from 500 to 3000 rpm and 250 to 2000 mm/min, respectively. An X-ray radiographic inspection was done to examine the defect formation in the welds as well as the visual inspection.

Figure 1 (a) and (b) show the appearance of FS welds made at 500 rpm and 1000 rpm of tool rotation speeds, respectively at the same welding speed, 250 mm/min. Longitudinal cracking occurred in the weld (a), but increasing tool rotation speed produced a defect-free weld as shown in (b) with a smooth weld surface.

Figure 2 (a) and (b) show typical microstructures on the cross section of FS welds made at 3000 rpm and 1500 rpm of tool rotation speeds, respectively at a constant welding speed of 500 mm/min. A cavity as an inner defect is observed in the stir zone in (a), which is not detected by a visual inspection so that non-destructive inspection, such as X-ray radiography is required. In Fig.2, (b) shows a defect-free weld. Regular orientation of Al_2O_3 particle distribution is clearly seen in Fig.2(c) in the base metal made by the forging, but not observed in the stir zone in Fig.2(d) due to the stirring action of the tool, though the distribution of Al_2O_3 particles is still uniform even in the stir zone. This suggests an adequate FSW condition enables a sufficient metal flow even with Al_2O_3 reinforcement particles.

Further studies on evaluating microstructural features and the mechanical properties of these FSW joints will be continued.

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Table 1 Chemical composition of 6061 MMC/Al2O3/10%.

	Chemical compositions								
Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Ni
Mass %	0.59	0.10	0.27	0.005	1.02	0.09	0.003	0.006	0.002

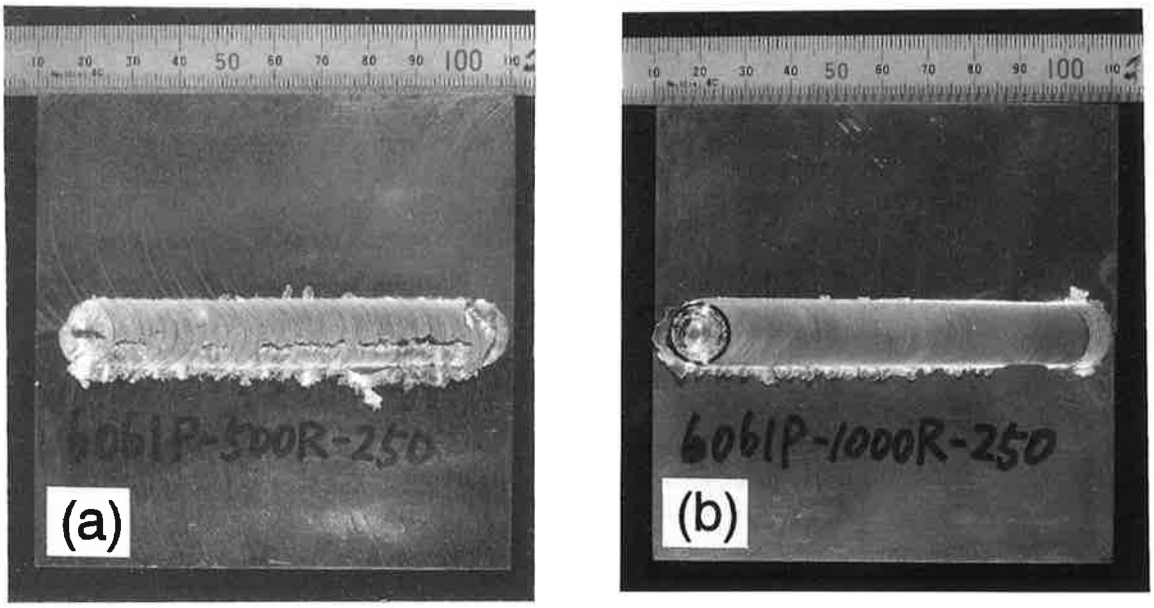

Fig. 1 Appearance of FS welds at the tool rotation speeds of 500 rpm (a) and 1000 rpm (b) with a constant welding speed of 250 mm/min.

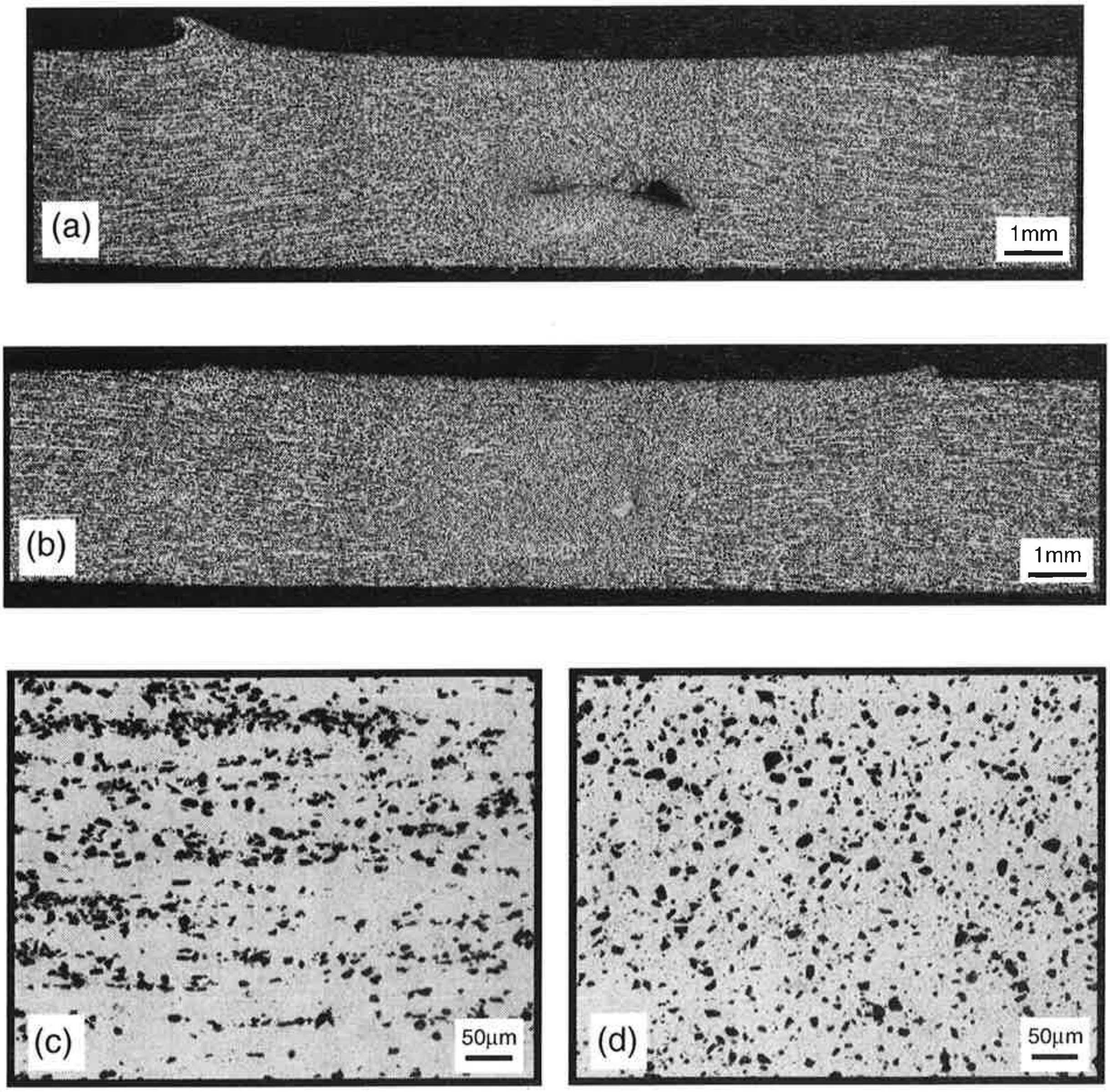

Fig. 2 Microstructures of FS welds on the cross sections; (a)3000 rpm and 500 mm/min, (b) 1500 rpm and 500 mm/min, (c) base metal in (b) at higher magnification and (d) the stir zone of (b) at higher magnification.