Friction Stir Welding of Aluminum Metal Matrix Composites

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Introduction

Fusion welding of aluminum metal matrix composites (Al-MMC's) is difficult due to the deleterious reactions between reinforcing hard particles and liquid aluminum. Since there is no melting during friction stir welding (FSW), problems associated with liquid-solid reactions are eliminated. This makes the FSW a potential process for joining Al-MMC's. The focus of this research was to compare the microstructural evolution in fusion welded Al-MMC's to that of the friction stir welded.

Procedure

In this research, three types of fusion welding; electron beam (EB), gas tungsten arc (GTA) and Nd:YAG (laser) were used to join two common aluminum metal matrix composites (Al-MMC's) and compared to that of friction stir welding (FSW). A 6061 aluminum reinforced with Al_2O_3 and another aluminum alloy 2124 reinforced SiC were used in this study (see Table 1). The welding parameters are given in Table 2. The welds were characterized with optical microscopy and hardness measurements. Phase stability in these alloys were also calculated using thermodynamic software and compared with the experimentally observed microstructure of the weld metal.

Table 1 Composition of Al-MMCs are given below [5]

Alloy	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Reinforcement
2124	0.2	0.3	4.4*	.6*	1.5*	0.25	0.1	0.15	20% SiC
6061	.6*	0.7	0.28*	0.15	2*	0.25	.2*	0.15	20% Al_2O_3

Table 2 Welding parameters used in this investigation

Joining Method	Energy Input (j/in)	Rotation Speed (rpm)	Translation Speed (ipm)
GTAW	4200	-	-
EBW	150	-	-
Nd:YAG	2750	-	-
FSW	-	500	2

Results and Discussion

The base metal microstructure of $6061/Al_2O_3$ and 2124/SiC alloys are shown in Fig 1. The reinforcement particles of both composites are uniformly distributed although there is a notable difference in the size and shape of particles. Even though three types of fusion welding methods were employed in this experimentation, similar microstructures were observed with respect to material type upon observation. In both cases the microstructure of the weld metal was different than that of the base metal.

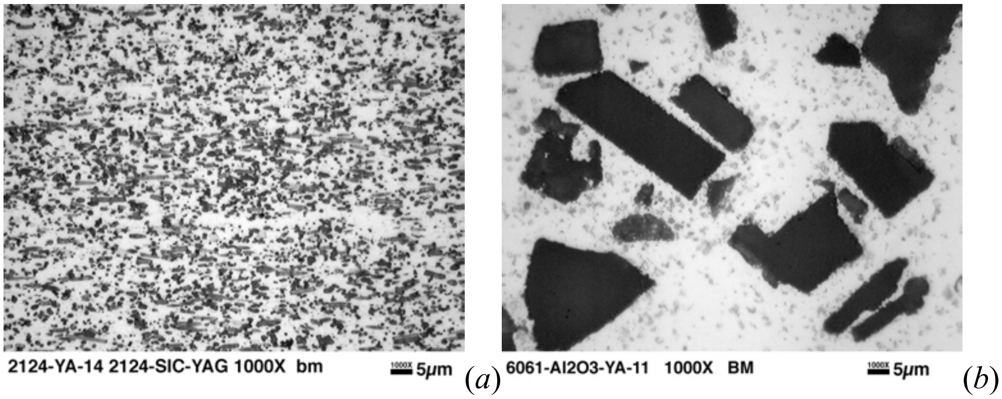

Fig. 1. Micrographs of base metal region from (*a*) 2124/SiC MMC and (*b*) 6061/Al_2O_3 MMC

Upon weld solidification in 2124/SiC alloys, coarse aluminum carbide (Al_4C_3) needles developed in the weld metal region along with particles of primary silicon $Si_{(s)}$ and eutectic aluminum (Fig 2*a*). The microstructural evolution of laser welded 2124/SiC is in agreement with previous research [1]. Due to the formation of aluminum carbide (Al_4C_3) and other phases the hardness of the weld metal increased and lead to the formation of the micro-cracks. In case of 6061 alloys, fusion welding eliminated the reinforcement particles of 6061/Al_2O_3 (Fig 2*b*), which lead to softening of the weld metal region. This was confirmed by hardness testing. It should be noted that in testing the hardness of 6061/Al_2O_3 there was a large variation of values due to sampling between Al_2O_3 particles and matrix. The elimination of Al_2O_3 in 6061 alloys and the formation of Al_4C_3 in 2124/SiC alloys were successfully correlated with the thermodynamic predictions carried out using ThermoCalc software.

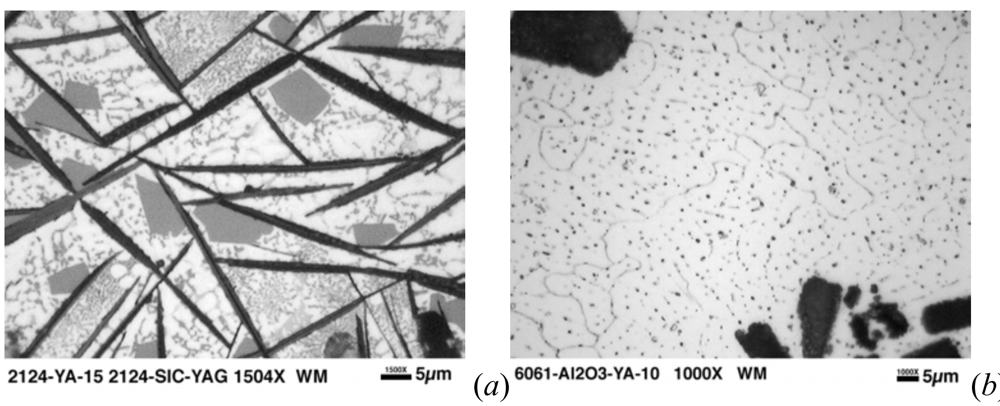

Fig. 2. Micrographs of laser weld metal region from (*a*) 2124/SiC MMC and (*b*) 6061/Al_2O_3 MMC

In contrast, the microstructure from friction stir welded 2124/SiC and 6061/Al_2O_3 alloys were different. The dynamically recrystallized zones (DXZ) of the friction stir welded samples are shown in Fig 3 at high magnification. In both images the reinforcement particles appear to be uniformly distributed and at this magnification there is no evidence that deleterious reactions have occurred in the DXZ and is in agreement with other research done in this area [2]. Previously, research has shown that secondary reactions occur in the friction-stir weldment [3,4], a similar investigation is underway to confirm this. Hardness measurements showed very little difference between the DXZ regions and the base metal in both the alloys. In addition, indication of particle alignment was seen in 2124/SiC alloy.

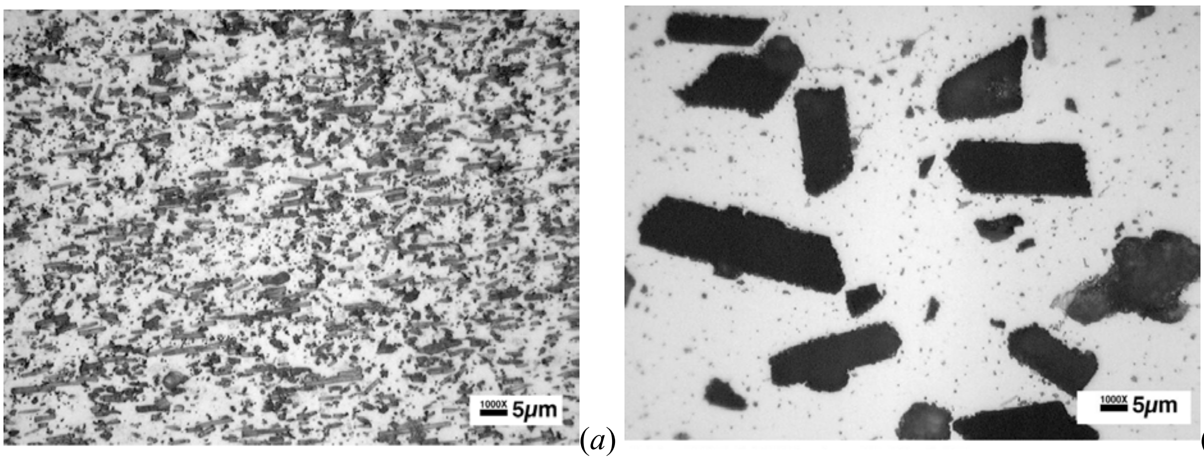

Fig. 3. Micrographs of friction stir weld region from (*a*) 2124/SiC MMC and (*b*) 6061/Al_2O_3 MMC

Conclusion

Fusion welding of Al-MMC's lead to deleterious reactions within the weld metal upon solidification. The formation of aluminum carbide (Al_4C_3) needles in the fusion welded 2124/SiC composite drastically increased the hardness of the weld metal. In the fusion welded 6061/Al_2O_3 composite, the reinforcement particles were eliminated completely resulting in a soft weld metal. Friction stir welding of Al-MMC's produced a homogeneous microstructure with a uniform hardness profile when compared to fusion welded Al-MMC's.

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