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Effect of welding parameters on microstructure in the stir zone of FSW joints of aluminum die casting alloy

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Abstract

The effect of the welding speed and the rotation speed on the microstructure in the stir zone has been investigated by measuring the Si particle distribution in the ADC12 alloy. The stir zone has fine recrystallized grains without dendritic structures, and the eutectic Si was uniformly dispersed in the stir zone. The size of the Si particles was statistically determined in the stir zone using image processing. The number of finer Si particles, which is formed by stirring of the tool probe, increases during the FSW. Finer Si particles are distributed more in the bottom than in the other regions, though the size of the Si particles in the base metal is the same in all the regions. The size of the Si particles decreases with increasing welding speed. However, it is not significantly affected by the rotation speed.

Keywords: Friction stir welding; ADC12; Aluminum die casting alloy; Eutectic silicon; Welding speed; Rotation speed

1. Introduction

Aluminum die casting alloys are made by the rapid injection of molten metal into metal molds under high pressure. These alloys have a dense and fine grain surface, which results in excellent wear and fatigue properties [1]. Approximately 85% of the aluminum die casting alloys are Al–Si–Cu alloys. These alloys provide a good combination of cost, strength, and corrosion resistance, together with the high fluidities that are required for easy casting. In recent years, aluminum die casting alloys are widely used in the automotive, electronics, machine and building industries due to their light and recyclable properties. However, the fusion welding of aluminum die casting alloys [2] is difficult due to the formation of welding defects such as blowholes and welding deformation as a result of the high coefficient of thermal expansion of the aluminum alloys. Because the welding defects result in decreased mechanical properties, this problem must be solved for use in practical applications.

From this point of view, Friction Stir Welding (FSW) was developed as a new joining process by The Welding Institute (TWI) in 1991 [3]. This method is a solid state welding process in which materials are joined by frictional heat. Therefore, FSW enables materials to be joined without the formation of blowholes. There is a high possibility that sound joints will be obtained. However, only a limited number of studies [4,5] have been done on cast aluminum alloys, although wrought aluminum alloys are being intensively studied [6–9]. In these studies, it has been become clear that the stir zone is comprised of a fine recrystallized grain without the cast structure; therefore, the FSW joint has better mechanical properties than that of conventional fusion welding [4,5]. In this study, the change in the microstructure by FSW has been further investigated, and particularly, the effects of the main welding

Table 1
Chemical compositions of the base material

Alloy	Chemical compositions/mass%									
	Cu	Si	Mg	Zn	Fe	Mn	Ni	Sn	Pb	Al
ADC12	2.35	11.82	0.17	0.56	0.81	0.18	0.04	0.02	0.06	Bal.

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Table 2
FSW tool size and welding parameters used in the experiments

Tool size			Welding parameters			
Shoulder diameter (mm)	Probe diameter (mm)	Probe length (mm)	Tool tilt (°)	Downforce (kN)	Rotation speed (rpm)	Welding speed (mm/min)
15	5	3.9	3	14.2	750–1750	250–1000

parameters, such as the welding speed and the rotation speed, on the microstructure in the stir zone are clarified by measuring the Si particle distribution in the ADC12 alloy.

2. Experimental procedures

Four mm thick ADC12 aluminum die casting alloy plates were used in this study. The gas content of the plate was about 2.6 ml/100 g Al. The gas in base metal was mainly hydrogen (H_2), and its gas content was measured by a vacuum melting process. Table 1 shows the chemical compositions of the base material used in this study.

In order to assess the range of the optimum FSW conditions for the ADC12 alloy, I-groove butt welding (50 mm (w) × 300 mm(l) × 2 piece) was performed using a load control type of FSW machine. The FSW tool has a columnar shape with a screw probe. SKD61 was used for the tool material. Table 2 shows the tool sizes and welding conditions. The tilt angle was 3°, and the tool plunge downforce was 14.2 kN. The tool rotation speed in the clockwise direction and the welding speed were varied from 750 to 1750 rpm and from 250 to 1000 mm/min, respectively. The plate top surface and groove surface were degreased with acetone just prior to welding. Mild steel was used for the backing plate.

After the FSW, a metallurgical inspection was performed on the cross-sections of the FSW joints. They were polished and etched with 5% hydrofluoboric acid (HBF_4) water solution for the optical microscopic (OM) and the scanning electron microscope (SEM) observations. In order to examine in detail the microstructure in the stir zone, the size of the Si particles was statistically determined in the stir zone using an image processing method (Image-Pro Plus ver.4.0).

3. Results and discussion

3.1. Macro- and microstructures of joints

Fig. 1 shows the macro- and microstructures of the cross-section of a sound joint under the optimum FSW conditions. The microstructures of the base metal (BM), the thermo-mechanically affected zone (TMAZ) and the stir zone (SZ) are also shown in Fig. 1(b), (c) and (d). The heat affected zone (HAZ) is not clearly seen. The ADC12 base

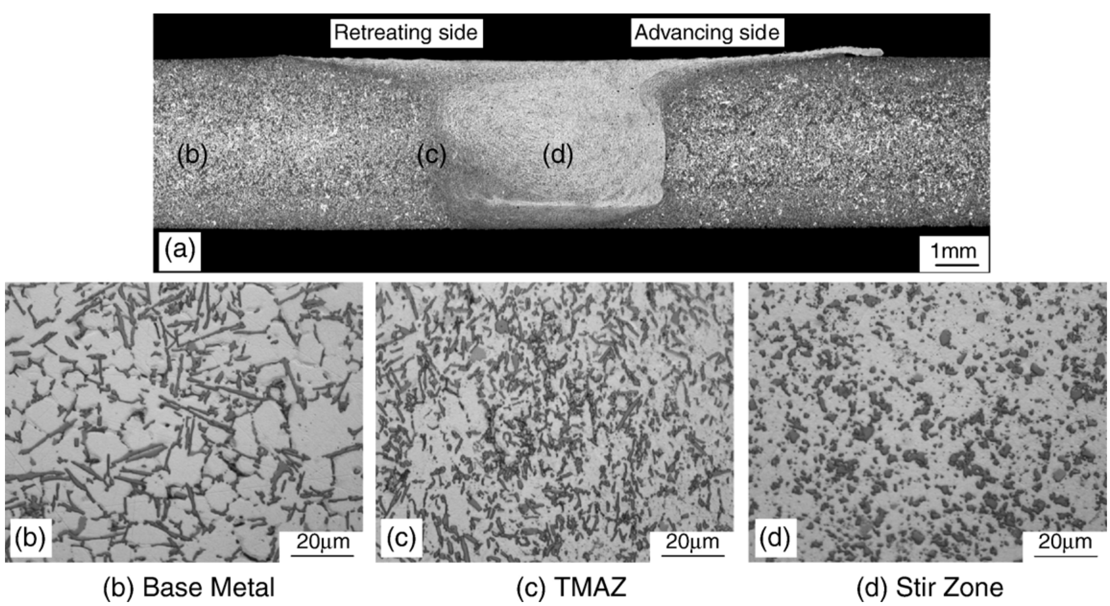

Fig. 1. Macro- and microstructures of FSW joint (14.2 kN, 1250 rpm—500 mm/min).

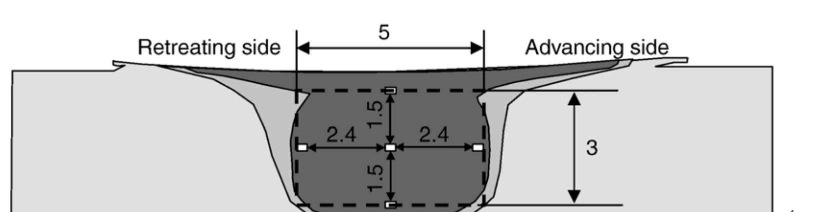

Fig. 2. Schematic illustration of observed positions of microstructure in the stir zone.