

Double-sided friction-stir welding of magnesium alloy with concave–convex tools for texture control

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ARTICLE INFO

Article history:

Received 27 November 2014

Revised 17 March 2015

Accepted 22 March 2015

Available online 23 March 2015

Keywords:

Magnesium alloy

Double-sided friction-stir welding

Texture

Tensile test

ABSTRACT

Double-sided friction stir welding (DFSFW) with the combined use of convex and concave tools (concave-DFSFW) was studied for the joining of a magnesium alloy. The sound joints made by the concave-DFSFW were possible under the appropriate conditions, and the joints had a characteristic structure of the stir zone different from the conventional friction stir welding with a one-sided tool rotation. The mean grain size of the stir zone decreased with the increasing rotation rate of the concave tool. This result indicated that the heat generation during the FSW is not only due to friction but also the plastic deformation. The complicated mixed metal flow that evolved by the convex tool randomized the texture in the stir zone, which provided the preferable tensile behavior.

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1. Introduction

The magnesium alloy is one of the light weight metals and its practical application are studied intensively [1–4]. Recently, a non-combustive magnesium alloy has been developed [5,6] and a highly strengthened alloy was developed by the microstructure control [7–9]. On the other hand, the joining process appropriate for these developed materials is also needed for their application. One of the preferable joining methods is friction stir welding (FSW) [10–13]. FSW is regarded as a solid state joining process, thus this method solves several problems which occur with the conventional fusion welding of low melting point alloys. Also, FSW can be regarded as a hot plastic deformation which forms the preferable microstructure such as a fine grained structure [14–19]. However, the crystallographic texture with a high concentration of orientations is evolved in the stir zone of the FSW joint [20] and this strong anisotropy causes the poor ductility of the joint. Consequently, the reversion of the FSW is required to realize the randomization of the texture.

One of the possible ways for this reversion is the use of multiple tools with an asymmetrical arrangement, such as double sided FSW (DFSFW) [21]. Chen et al. [22] reported the application of DFSFW for a magnesium alloy, in which the combination of the tool with a probe and that without a probe was applied, and the arrangement of the tilting angle was set asymmetrically. They

clarified that this arrangement of the tool can somehow randomize the texture followed by the optimization of the mechanical properties of the joint.

In addition, the FSW tool provides the heat input as well as the metal flow to the joint, and the shape of the tool is one of the most important components which determines the quality of the joint [23]. It is predictable that the complicated shape, such as the attachment of the convex part, produces a more mixed metal flow followed by the additional randomization of the texture. Consequently, the aim of this study is to clarify the efficiency of the DFSFW with the combination of the concave and convex tool as schematically shown in Fig. 1 for the joint of the magnesium alloy.

2. Experimental procedures

AZ31B magnesium alloy wrought sheets were used. The dimensions of the sample are a width of 75 mm, a length of 150 mm and a thickness of 4 mm. The microstructure of the base metal is an equiaxed grained structure whose mean grain size is 103.5 μm . FSW was conducted using a position control type machine. The FSW tools had the dimensions shown in Fig. 2. Both tools were made of tool steel (JIS-SKD61) and arranged as shown in Fig. 1. The upper tool had a shoulder with a slope of 10° and the threaded probe with a cylindrical shape. This shape is typical for the FSW of magnesium [23]. The lower tool had a concave shape with a hole. The welding parameters in this study are shown in Table 1. The tilted angle was 3° for the upper tool and the lower tool was not

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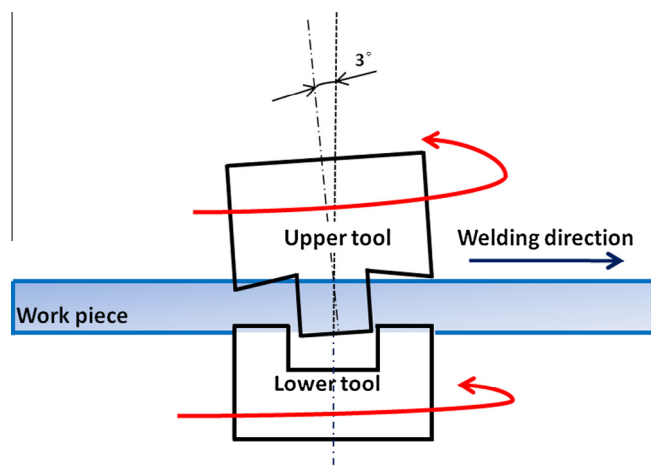


Fig. 1. Schematic illustration of the DFSW with a concave lower tool.

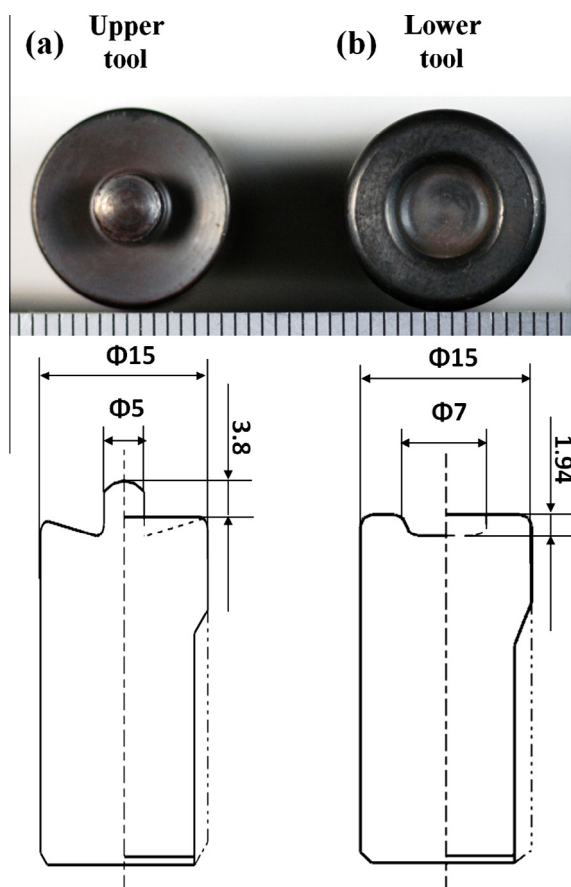


Fig. 2. Photos and schematic illustrations of the upper tool (a) and the lower tool (b).

tilted. Both tools were rotated counter clockwise. The welding direction was parallel to the wrought direction.

In order to determine the possible joining conditions, the first trial was conducted at several rotation rates ranging from 300 rpm to 600 rpm. Both the upper and lower tools had the same rotation rate. For this first trial, however, the hole in the lower tool was filled with magnesium at a rotation rate of 600 rpm as shown in Fig. 3, and the joining could not be completed. This result indicated that a relatively lower rotation rate is preferable for the

Table 1
Welding parameters.

	Welding parameters			
	Tool tilt (°)	Rotation speed (rpm)	Rotation direction	Travel speed (mm/min)
Upper tool	3	300	CCW	500
Lower tool	0	200, 300	CCW	



Fig. 3. Appearance of the lower concave tool with sticking materials after the DFSW at a rotation rate of 600 rpm.

DFSW. In this study, the rotation rate of the upper tool remained constant at 300 rpm; whereas the rotation rate of the lower tool was 200 rpm or 300 rpm. The joining speed was 500 mm/min. In order to obtain the reference data, the DFSW with a flat tool in place of the convex tool was also examined. The flat tool had a diameter of 15 mm without any probe or hole. The rotation speed of both the convex and flat tools was 300 rpm and the joining speed was 500 mm/min. A conventional one-sided FSW was also conducted only with the upper tool. In this paper, the DFSW with the concave tool is defined as 'concave-DFS' and that with the flat tool is called 'flat-DFS'.

The microstructures of the joints were examined by optical microscopy and scanning electron microscopy (SEM) equipped with an electron back scattered diffraction (EBSD) system. The EBSD measurement was conducted on the cross section plane which is parallel to both the normal direction (ND) and the transverse direction (TD) of the sheet. The tensile test was conducted at room temperature at a constant tensile speed of 1 mm/min. The tensile test pieces were cut with the tensile direction parallel to the welding direction (WD). The dimensions of the tensile test piece are shown in Fig. 4.

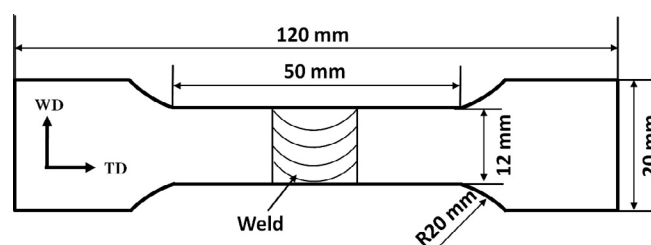


Fig. 4. Tensile specimen.

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