Materials Science & Engineering A 684 (2017) 470–479

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Effect of tool dimensions and parameters on the microstructure of friction stir welded aluminum 7449 alloy of various thicknesses

N. Martinez[a], N. Kumar[a], R.S. Mishra[a,*], K.J. Doherty[b]

[a] Center for Friction Stir Processing, Department of Materials Science and Engineering, University of North Texas, Denton, TX 76203, USA
[b] Weapons and Materials Research Directorate, US Army Research Laboratory, Aberdeen Proving Grounds, MD 21005, USA

A R T I C L E I N F O

Keywords:
Aluminum 7449
Friction stir welding
Microstructure
Heat gradient
Natural aging
GP zones

A B S T R A C T

Friction stir welding is a solid state joining technique in which no melting is involved. This technique is very attractive for high strength aluminum alloys, since these are difficult to weld by conventional means. Al-Zn-Mg-Cu alloys are strengthened mainly by metastable η' precipitates. Microstructural evaluation was done on an aluminum 7449 alloy of various thicknesses after friction stir welding. Microhardness, TEM, and DSC were done to characterize the welds. The effects of natural aging and artificial aging were studied to understand re-precipitation of the strengthening precipitates in the weld. A noticeable heat gradient was observed. Furthermore, tool dimensions and the parameters chosen influence the dissolution and re-precipitation of the weld, with negligible dependence on the plate thickness.

1. Introduction

Friction stir welding (FSW) is a relatively new technique for joining metal plates [1–3]. A non-consumable rotating tool is used to stir the material of two separate plates into a single joint. FSW is a great option for the Al-Zn-Mg-Cu (7XXX) alloys, since these are difficult to weld using conventional fusion methods. Friction stir welding shows no defects (such as pores and hot shortness cracks) that are normally associated with conventional fusion welding.

The 7XXX aluminum series derive their strength primarily from the η' precipitate [4,5]. This precipitate consists of the stoichiometric composition $MgZn_2$ and is formed from the supersaturated solid solution (sss) by the following sequence:

α (sss) → GP Zones → Metastable η′ → Stable η

GP zones have been observed to form at low temperatures (25–125 °C). However, they dissolve at a temperature range between 100–125 °C, whereas the main strengthening particle η' usually forms at higher temperatures (120–290 °C) [6].

The microstructural evolution of Al-Zn-Mg-Cu alloys after friction stir welding has been studied extensively [6–11]. The nugget experiences large dissolution of the existing precipitates due to the high heat and intense plastic deformation; while re-precipitation occurs during the low temperature regime of the weld. It is believed that in the heat affected zone (HAZ), the elevated temperatures leads to a loss in strength due to coarsening of the existing precipitates. Efforts have been made to inhibit coarsening in the HAZ by obtaining colder runs. Higher traverse speeds along with lower rotational rates have produced welds with very good joint efficiency [9]. Furthermore, a heat gradient has been observed in thicker aluminum 7449 welds [10]. It was found that the microstructure and hardness profiles are heavily dependent on thickness position along the depths of the weld due to this heat gradient. Fuller et al. have studied extensively the natural aging effects of aluminum 7050 and 7075 alloys [6]. They showed that a recovery in strength occurs after natural aging of a friction stir weld.

Several authors have modeled friction stir welds of aluminum 7xxx series alloys [12–16]. Equations were derived to determine the amount of heat produced during a run. The pin heat generation contribution was approximately 20% of the total heat generated, but the shoulder produced the majority of the heat during a weld.

Friction stir welds of various thicknesses of an aluminum 7449 alloy were investigated in this work. Even though the literature shows work done on specific welds of Al-Zn-Mg-Cu alloys, each with different thickness, there has been no direct comparison between the microstructure of the welds and its dependence on plate thickness. The main objective in this work was to observe the tools' effect on the microstructure with varying thicknesses. Emphasis was placed on the nugget and heat affected zone (HAZ) of the weld [9,10]. The lowest strength in the heat affected zone is known as the HAZ minimum. Particular attention was placed at this region, since failure occurs in this region. The strengthening mechanisms were observed after short term artificial aging and 12 months of natural aging.

* Corresponding author.

http://dx.doi.org/10.1016/j.msea.2016.12.077
Received 16 September 2016; Received in revised form 16 December 2016; Accepted 17 December 2016
Available online 20 December 2016
0921-5093/

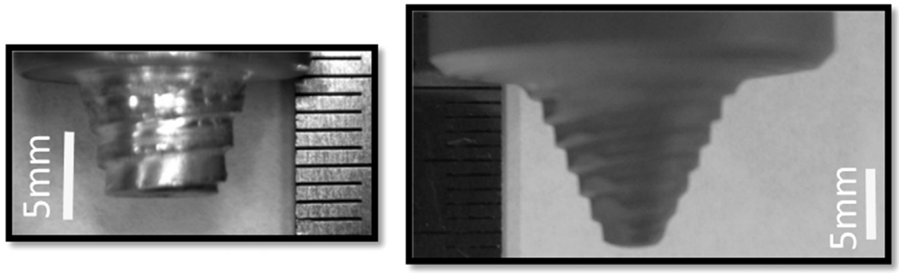

Fig. 1. Smaller tool and larger tool used in the different friction stir welds.

2. Materials and methods

2.1. Materials

The as-received plate consisted of a 40 mm thick 7449 aluminum alloy in a slight overaged condition. The plate was machined down to thinner plates. The 1st plate thickness was 7.2 mm, the 2nd plate thickness was 11.7 mm, and the 3rd thickness was 17.5 mm. Accordingly, in this paper, the terms “thin”, “thick”, and “thickest” will be used. A 4th plate was machined down to 14 mm, and a copper backing was used during the weld to remove heat from the bottom. This will be referred to as the “Cu backing” plate.

Two different tools were used in this work (see Fig. 1), with the dimensions given in Table 1. Throughout this paper, the small tool will be referred to as the “smaller” tool, and the large tool will be referred to as the “larger” tool.

Two different aging treatments were performed on the welds. Some of the welds were artificially aged in an air furnace at 121 °C for 24 h, and some of the samples were allowed to naturally age at room temperature for 12 months. Table 2 provides the details of the tool used and plate thickness, along with the rotational rate and traverse speed (RPM/IPM). The smaller tool was used for the “thin” and “thick” plates. The heat generated ranged from hot to cold (the 600/2 being the hot run and 300/8 being the cold run). The larger tool was used on the “thickest” and “Cu backing” plates while the parameters used were kept the same (same amount of heat applied).

2.2. Microstructural characterization

Optical microscopy and scanning electron microscopy (SEM) were used to characterize the grain structure and intermetallic particles of the as-received material. An FEI Quanta 200 environmental scanning electron microscope was used for this work. The samples were polished followed by etching with Keller's Reagent. The energy dispersive spectrometer (EDS) was used to analyze the intermetallic particles present in the as-received alloy.

Hardness profiles of the weld in the transverse cross section was determined using Vickers micro indention with a 300 g load. The dwell time was 10 s. Transmission electron microscopy (TEM) was carried out on a FEI Technai™ operating at 200 kV. TEM was used to observe precipitates of the base metal and some of the welds.

A Netzsch 204 F1 Phoenix was used to perform differential scanning calorimetry (DSC) on the base metal and specific areas (nugget and HAZ) of some of the welds. The precipitate evolution of the welds was analyzed. The temperature ranged from 25 °C up to 550 °C (heating rate was 10 °C/min for the heating and cooling stages).

Table 1
Tools used and the dimensions.

	Smaller tool	Larger tool
Shoulder diameter	15.8 mm	25 mm
Pin root diameter	8.8 mm	13 mm
Pin tip diameter	6.0 mm	3.5 mm
Pin height	6.2 mm	11 mm

Table 2
Tools used, plate thickness and parameters.

Plate	Thickness	Tool used	RPM/IPM
Thin	7.2 mm	Smaller	600/2
Thick	11.7 mm	Smaller	350/5 and 300/8
Thickest	17.5 mm	Larger	200/4
Cu backing	14 mm	Larger	200/4

3. Results

3.1. Grains structure

Fig. 2 shows the rolled microstructure for aluminum 7449 base material. The average grain size was 60 µm in surface 1; 20 µm in surface 2; 12 µm in surface 3. The grains appear to be flattened and elongated, which most likely occurred during the rolling process.

Fig. 3 shows the SEM images of the coarse intermetallic particles present in the base material. Table 3 provides the EDS chemical composition data of the base metal and the constituent particles. From the EDS analysis, the coarse intermetallic particles in this alloy are Al_7Cu_2Fe.

3.2. Microhardness

3.2.1. Depth of weld microhardness

Fig. 4 shows the hardness profile of the original 40 mm metal plate in the as received condition. No significant variation in hardness (~195 HV) was observed through the thickness of the plate.

Individual plates were machined down to thinner plates and were

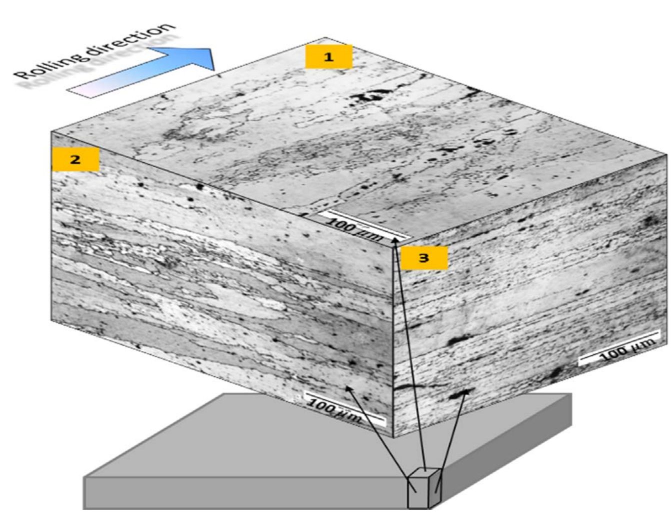

Fig. 2. Optical microscope images of Al 7449 base metal.