Journal of Alloys and Compounds 713 (2017) 51–63

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Microstructural variation due to heat gradient of a thick friction stir welded aluminum 7449 alloy

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, U.S. Army Research Laboratory, Aberdeen Proving Grounds, MD 21005, USA*

ARTICLE INFO

Article history:
Received 15 January 2017
Received in revised form
3 April 2017
Accepted 13 April 2017
Available online 14 April 2017

Keywords:
Al7449
Solid-state welding
Friction stir welding
Precipitation strengthened alloy
Microstructure
Nugget
Heat gradient
Fine precipitates

ABSTRACT

Welding of precipitation strengthened (PS) aluminum alloys leads to a knockdown of mechanical properties in the weld zone. Reduced mechanical properties in the weld region, impact the design of load-bearing structures resulting in heavier engineering components. So far even friction stir welding (FSW), an advanced solid-state welding technique, has not solved the issue of a reduction in mechanical properties of PS aluminum alloys, especially in thick plates. This issue remains unresolved due to limited choice of processing conditions and the lack of clear insight into the FSW of precipitation strengthened Al alloys. The present study combines experimental and computational tools to maximize the strength of the welded structure of a PS Al 7449 alloy. A series of welds were made using various parameters, which ranged from cold runs (low rotational rate and high traverse speed) to hot runs (high rotational rate and low traverse speed). Even though the heat gradient is observed for all welds, and a difference is observed at the top and bottom of the nugget for all welds, a set of parameters (150 RPM/ 8 IPM) was chosen for microstructural evaluation. This particular combination showed significant higher hardness values at the bottom of the nugget compared to the base metal. The selection of FSW processing parameters were guided by a calibrated finite element thermal model of FSW. Because of the plate thickness, a significant heat gradient exists through the thickness of the weld, resulting in microstructural variations in the welded zone. Differential scanning calorimetry and transmission electron microscopy captured the microstructural evolution in the welded structure. Mechanical properties were measured using Vickers microhardness on the welded plates. The heat affected zone (HAZ) and the nugget were of primary interest. An improvement in HAZ has been observed after natural aging, while exceptionally high strength was observed at the bottom of the nugget region independent of the aged condition.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

Friction stir welding (FSW) is a solid state technique which uses friction to join two separate plates together [1]. It has emerged as the preferred method for welding precipitation strengthening (PS) aluminum alloys. FSW is very attractive for the aluminum 7XXX (Al–Zn–Mg–Cu) series, since these are difficult to weld by conventional techniques. These alloys derive their strength primarily from fine η' ($MgZn_2$) precipitates. When heat is applied, the precipitates either dissolve or coarsen, and result in degradation of the mechanical properties of the weld [2-7]. FSW is a solid-state, thermo-mechanical process; no melting of the material is involved. Thus, FSW overcomes the issues associated with liquid phase processing such as the presence of a large number of defects and the formation of detrimental phases.

Texture, precipitation kinetics, and grain growth can be modified by FSW [2-8]. Different thermal cycles and deformation during the weld lead to three additional microstructural regions: the stir zone (or nugget), the thermo-mechanical affected zone (TMAZ), and the heat affected zone (HAZ). In the stir zone, intense material flow and frictional heating take place around the tool [5-6], thereby resulting in a fine recrystallized grain structure due to the intense plastic deformation [7,8]. The TMAZ serves as the transition between the nugget and the HAZ. The HAZ is the region that

---

[*] Corresponding author.
E-mail address: rajiv.mishra@unt.edu (R.S. Mishra).

http://dx.doi.org/10.1016/j.jallcom.2017.04.147
0925-8388/© 2017 Elsevier B.V. All rights reserved.

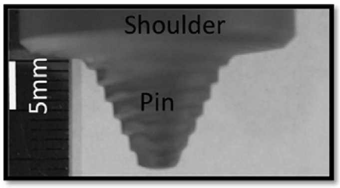

Fig. 1. Tool used for FSW run.

experiences a temperature rise, but no plastic deformation. This temperature rise dissolves or coarsens the strengthening precipitates, and failure usually occurs in this zone. The lowest hardness value in this region is known as the HAZ minimum.

When friction stir welding Al–Zn–Mg–Cu alloys, a balance between optimal re-precipitation in the nugget and minimal dissolution/coarsening in the HAZ is crucial. The microstructural evolution in the Al 7449 alloy after friction stir welding has been studied by a few authors [2-4]. Due to the heat and intense plastic deformation in the nugget, there is extensive dissolution of the existing precipitates and therefore a high amount of solute is in solution. During the cooling stage of the weld cycle, re-precipitation occurs from this super saturated solid solution. Post weld heat treatments lead to improvements in strength of the nugget [2-12]. In the HAZ, heat during the welding leads to dissolution and coarsening of η' ($MgZn_2$) precipitates simultaneously [4,9-10]. Dumont et al. [4] reported that low rotational rate (RPM) and faster traverse speeds (IPM) lead to improved joint efficiency in the welds. A post weld heat treatment typically does not lead to strength recovery in the HAZ, but the magnitude of knockdown in strength can be reduced significantly by using auxiliary cooling methods. Furthermore, natural aging has been shown to lead to recovery in strength in both the nugget and HAZ [11].

So far, even advanced welding techniques like friction stir welding have not solved the issue of a reduction in mechanical properties in the welds of PS Al alloys, especially in thick aluminum plates. In this work, FSW processing parameters were chosen and supplemented by a calibrated finite element thermal model of the FSW process. A relatively low tool rotational rate was used with the intention of providing lower heat at the top by the shoulder of the tool, and high enough traverse speed was used to prevent a wide HAZ. Furthermore, a high thermal conducting plate (copper) was used at the bottom of the weld to remove heat. Although, similar setups have been reported [13], the combination of low rotational rate, high traverse speed and copper backing on thick aluminum plates has not been reported.

Since the aforementioned work plate is sufficiently thick, a significant heat gradient was observed during the weld. Several authors have reported that a significant heat gradient in thick aluminum welds results in variations in the microstructure at the top and bottom of the weld [2,13,14], which is unavoidable because of the nature of the heat source and heat sink during FSW. At present, no detailed analysis has been performed (nor reported in the literature) to determine the rationale for microstructural differences between the top and bottom of the nugget. In this work, the heat gradient (from the thick work plate) along with a copper backing resulted in two separate microstructures in the nugget. The bottom of the nugget has smaller precipitates, finer grains/subgrains, and higher dislocation density compared to the top of the nugget. Furthermore, large improvements in hardness were observed after three months of natural aging at the top and middle of the weld; while the bottom of the nugget shows higher strength than the parent material, independent of the aging condition. Thus, in an effort to understand the effect of FSW on thick plates, a thorough analysis was done on the top and bottom of the nugget of a 13 mm thick aluminum 7449 weld.

2. Materials and methods

2.1. Materials

The alloy of interest is a relatively high strength aluminum 7449 alloy, which was received in an over aged condition (base metal hardness ~ 155 HV). The tool used in this work had a shoulder diameter of 25 mm and a root pin diameter of 11 mm. The pin tip diameter was 3.5 mm and the pin height was 11 mm (Fig. 1). The as-received plates (original thickness was 40 mm) were machined to a thickness of 13 mm. The rotational rate and the traverse speed were 150 revolution per minute (RPM) and 8 inches per minute (IPM), respectively. A high thermal conductive backing plate (copper) was used at the bottom of the weld to remove heat. Since copper has a higher thermal conductivity (410 W/m-K) compared to steel (16 W/m-K), it allowed efficient heat removal. The selection to use copper instead of another high thermal conducting metal was largely due to the lower cost of copper. Fig. 2 shows the setup used for this work.

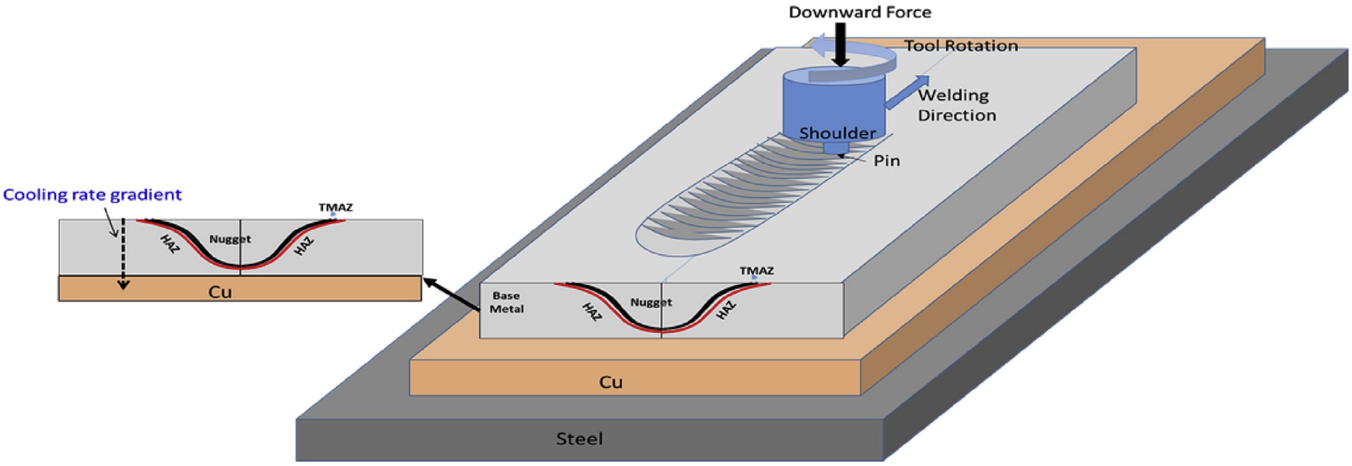

Fig. 2. Setup used for the FSW run.

Download English Version:

https://daneshyari.com/en/article/5459034

Download Persian Version:

https://daneshyari.com/article/5459034

Daneshyari.com