Available online at www.sciencedirect.com
ScienceDirect
Journal of Magnesium and Alloys 000 (2018) 1–6
www.elsevier.com/locate/jma

Full Length Article

Joining of AZ91 Mg alloy and Al6063 alloy sheets by friction stir welding

B. Lakshmana Prasad [a], G. Neelaiah [a], M. Gopi Krishna [a], S.V.V. Ramana [a], K. Sai Prakash [a], G. Sarika [a], G. Pradeep Kumar Reddy [b], Ravikumar Dumpala [c,*], B. Ratna Sunil [a,*]

[a] Department of Mechanical Engineering, Rajiv Gandhi University of Knowledge Technologies (AP-IIIT), Nuzvid 520201, India
[b] Department of Mechanical Engineering, Vignana Bharathi Institute of Technology, Hyderabad 501301, India
[c] Department of Mechanical Engineering, Visvesvaraya National Institute of Technology, Nagpur 440010, India

Received 13 May 2017; received in revised form 19 December 2017; accepted 25 December 2017
Available online xxx

Abstract

In the present work, the effect of process parameters on joining of AZ91 Mg alloy and Al6063 aluminum alloy sheets during friction stir welding (FSP) was studied. A successful joint was achieved at 1100 r.p.m. tool rotational speed and 25 mm/min tool travel speed. Combination of tool rotational speed and tool travel speed has observed a profound effect on the material flow mechanisms at the nugget zone. From the microstructural studies, the joint formation was observed as mainly due to mechanical mixing of the materials. The level of metallurgical continuity at the nugget zone was observed as poor and a sharp interface at the joint was noticed. The microhardness measurements across the weld joint also revealed the lack of establishment of a perfect metallurgical bonding. X-ray diffraction analysis of weld zone showed presence of both magnesium and aluminum. Hence from the preliminary observations, it can be understood that the joining of AZ91 Mg alloy and Al6063 alloy can be achieved by FSP; however, complex issues in material mixing still need further investigations.

Keywords: Friction stir welding; Dissimilar joints; Magnesium; Aluminum; Nugget zone.

1. Introduction

Obtaining permanent joint between two dissimilar metals is essential in developing low weight high strength structures with improved fuel economy in automobile applications. However, joining of dissimilar metals by fusion welding techniques is technically challenging in the welding industry [1]. Aluminum (Al) alloys and magnesium (Mg) alloys are well known non-ferrous metallic systems which are being used widely in structural applications. The necessity of joining dissimilar metals is gradually being increased in modern designing and manufacturing industry. In this context, joining of two dissimilar non-ferrous metals can open wide scope for several applications in the manufacturing industry. Joining of dissimilar alloys of the same base material is difficult [2]. If the base materials are chemically different for example Al–Mg, Al-steels and Mg-steels, then the welding of corresponding alloys is further complex [3,4]. The melting point, rate of heat conduction, temperature dependent plastic deformation and crystal structure of base materials are a few influencing factors which make joining of Al alloys and Mg alloys as complex in nature by liquid state methods [1,3]. On the other hand, friction stir welding (FSW), a solid state method developed to join similar and dissimilar metals without melting the material is gaining wide attention in solid state welding of dissimilar metals [5,6].

In Mg based dissimilar welding research, most of the works were done by using one of the AZ series Mg alloys as base material. Chen and Nakata [7] successfully joined AZ31 Mg alloy and zinc coated low carbon steel and reported that the joint was formed due to the formation of a low temperature melting eutectic phase which improved the

* Corresponding authors.
E-mail addresses: ravikumardumpala@mec.vnit.ac.in (R. Dumpala), bratnasunil@rgukt.in (B.R. Sunil).

https://doi.org/10.1016/j.jma.2017.12.004
2213-9567/

Please cite this article as: B.L. Prasad et al., Joining of AZ91 Mg alloy and Al6063 alloy sheets by friction stir welding, Journal of Magnesium and Alloys (2018), https://doi.org/10.1016/j.jma.2017.12.004

Table 1
Chemical composition of the base materials used in the present work.

Alloy	Elements % by wt.							
	Mg	Al	Zn	Si	Mn	Cr	Fe	O
Al6063	0.6	97.5	0.01	0.6	0.02	0.01	0.13	0.02
AZ91	90.2	8.7	0.95	–	0.05	–	0.01	0.05

diffusion between the magnesium alloy and the steel at the joint. Sato et al. [8] joined AA5083 aluminum alloy with AZ31 magnesium alloy and formation of Al_3Mg_2 as embedded in a eutectic of α-Mg and $Mg_{17}Al_{12}$ was noticed with good lap shear strength of the joint. Similarly, Yamamoto et al. 2009 [9] also reported the formation of intermetallic layer consisting of $Mg_{17}Al_{12}$ and Al_3Mg_2 in the dissimilar weld zone of Al5083 and AZ31 alloys. Simoncini and Forcellese [10] successfully joined AA5754 and AZ31 thin sheets by FSW and observed lower stress and ductility levels for the welded samples compared with the base materials at all process parameters. Yan et al. [11] joined AZ31 Mg alloy sheets with 1060 Al alloy by FSW and the interface was observed with a lamellae structure. Furthermore, centerline crack was observed in the weld joint due to the formation of Al_3Mg_2 and $Al_{12}Mg_{17}$ phases in the weld region. Similar brittle mode fracture was also reported by Masoudian et al. [12] in the weld joint of AZ31-O Mg alloy with 6063-T6 Al alloy developed by FSW due to the complex mixture of the base materials in the stir zone. Additionally, the tensile strength of the weld material was measured as decreased compared with both the base materials. Formation of intermetallics (between Mg and Al) was also observed by Liyanage et al. [13] during the welding of Al6111 alloy with low carbon steel and AM60 Mg alloy with DP600 dual phase steel.

In our previous work, AZ31 and Al6063 Mg alloys were successfully joined by FSW and deteriorated corrosion performance was observed at the joint due to galvanic corrosion [14]. As observed in the previous work, the important mechanism by which the joint was established in the dissimilar metals is mechanical mixing of the material with and without alternate layers of base materials [15,16]. However, the information on welding of AZ91 Mg alloy and Al alloys is insufficient in the literature. Therefore in the present study, AZ91 magnesium alloy and Al6063 aluminum alloy were selected to join by FSW. Different combinations of tool rotational speeds and tool travel speeds were adopted to obtain a successful joint. The important issues which dictate the material flow in dissimilar metal welding were studied with the help of the microstructural observations and microhardness measurement at the weld joint.

2. Experimental details

AZ91 Mg alloy (Exclusive Magnesium, Hyderabad, India) and Al6063 alloy (Metro Metals, Vijayawada, India) sheets of size $100 \times 50 \times 4$ mm were prepared for the experiments. Chemical composition of the base materials are shown in Table 1. The workpieces were fixed on the work table of

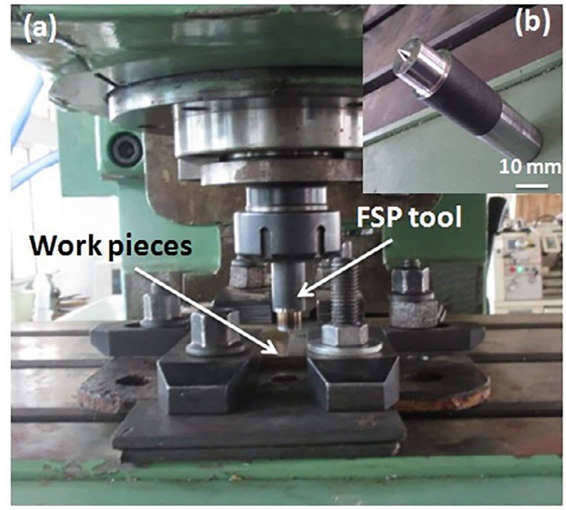

Fig. 1. Photographs showing (a) the work pieces fixed on the work table of the universal milling machine and (b) FSW tool used in the present work.

a universal milling machine (Bharat Fritz Werner Ltd., India) and the process was carried out by using an FSW tool made of H13 tool steel with 15 mm shoulder diameter consisting a tapered pin with 3–1 mm taper for a distance of 3 mm. Fig. 1 shows the photograph of the equipment and FSW tool used in the present study. Welding was carried out at different tool rotational speeds (1100, 1400, 1600 and 1800 rpm) and travel speeds (16, 25 and 40 mm/min). The process parameters were selected based on the literature and also considering the available speed and feed variations in the equipment used to carry out the experiments [17]. For every combination of processing parameters, the weld joint was obtained and examined. Successful joint, without defects was obtained at 1100 rpm with 16 mm/min feed.

Specimens of size $30 \times 10 \times 4$ mm^3 were cut across the weld direction and microstructural observations were carried out. Initially, the specimens were polished with different grades of emery papers up to 2000 grade followed by polishing with alumina paste. Then the specimens were polished with diamond paste using disc polishing equipment. After every step, the specimens were properly cleaned with ethanol to remove any residues resulted due to the previous polishing step. The polished specimens were chemically etched with picric acid reagent and optical microscope images were obtained using an inverted polarized optical microscope (Leica, Germany). For hardness measurements (Omnitech, India), the specimens of size $30 \times 20 \times 4$ mm^3 were cut across the weld joint. Measurements were obtained for every 1 mm in such a way that the base material, heat affected zone (HAZ), thermo mechanically affected zone (TMAZ) and nugget zones are measured. During measurement, 100 g load was applied for a dwell period of 15 s. X-ray diffraction (XRD, Bruker advanced D8, USA) analysis was carried out for base materials and the weld joints. Scanning was carried out from 20° to 80° using CuKα radiation with 0.1° step size.