Available online at www.sciencedirect.com

ScienceDirect

Defence Technology 11 (2015) 292–298

www.elsevier.com/locate/dt

Friction welding of AA6061 to AISI 4340 using silver interlayer

SURESH D. MESHRAM*, G. MADHUSUDHAN REDDY

Defence Metallurgical Research Laboratory, Kanchanbagh, Hyderabad 500058, India

Received 27 March 2015; revised 17 May 2015; accepted 19 May 2015
Available online 26 June 2015

Abstract

The present work pertains to the study on joining of AA6061 and AISI 4340 through continuous drive friction welding. The welds were evaluated by metallographic examination, X-ray diffraction, electron probe microanalysis, tensile test and microhardness. The study reveals that the presence of an intermetallic compound layer at the bonded interface exhibits poor tensile strength and elongation. Mg in AA6061 near to the interface is found to be favourable for the formation and growth of Fe_2Al_5 intermetallics. Introduction of silver as an interlayer through electroplating on AISI 4340 resulted in accumulation of Si at weld interface, replacing Mg at AA6061 side, thereby reducing the width of intermetallic compound layer and correspondingly increasing the tensile strength. Presence of silver at the interface results in partial replacement of Fe—Al based intermetallic compounds with Ag—Al based compounds. The presence of these intermetallics was confirmed by X-ray diffraction technique. Since Ag—Al phases are ductile in nature, tensile strength is not deteriorated and the silicon segregation at weld interface on AA6061 in the joints with silver interlayer acts as diffusion barrier for Fe and further avoids formation of Fe—Al based intermetallics. A maximum tensile strength of 240 MPa along with 4.9% elongation was obtained for the silver interlayer dissimilar metal welds. The observed trends in tensile properties and hardness were explained in relation to the microstructure.

Keywords: Dissimilar metal weld; Interlayer; Friction welding; Intermetallics; Microstructure; Tensile strength

1. Introduction

Several situations arise in industrial practices which call for joining of dissimilar metals. The joining of dissimilar metals is commonly done to satisfy different requirements for effective and economic utilization of the special properties of each material for enhanced performance. Dissimilar metal joints can be made successfully if there is a mutual solubility between the two metals. Otherwise, using interlayer/layers that is/are compatible with each other is required to produce joint. For dissimilar metals having widely different coefficients of thermal expansion, the joint may fail due to thermal fatigue either during solidification or soon thereafter. This is because the internal stresses are setup in the intermetallic zone, which tends to be extremely brittle. In the case of two metals having different melting temperatures or thermal conductivities, the process of welding is complicated because one metal is molten before the other. There is a continuing demand for reliable methods of joining dissimilar metals and alloys. For example, welding is irreplaceable in the manufacture of vacuum system made of dissimilar metals for cryogenic engineering. Recently, the range of combinations of the dissimilar metals, used in welded structures, has greatly increased and is continuous to increase. Joining of aluminium with steel finds its application in the fields of cryogenic engine, space craft and automobile. However, the fusion welding of aluminium to steel is difficult due to the formation of brittle intermetallic compounds at the interface [1–4]. The solid state joining of steel directly to aluminium also gives an unsatisfactory product because of incompatibility of physico-chemical properties of the two metals to be bonded [5]. The interdifusion of Al and Fe often yields a series of brittle intermetallic compounds at the interface. Such brittle layers cannot sustain the strain of subsequent metal working

* Corresponding author. Tel.: +91 4024586433; fax: +91 4024342697.
E-mail addresses: suresh_uor@yahoo.co.in (S.D. MESHRAM), gmreddy_dmrl@yahoo.co.in (G. MADHUSUDHAN REDDY).
Peer review under responsibility of China Ordnance Society.

http://dx.doi.org/10.1016/j.dt.2015.05.007
2214-9147/

operation which results in the internal rupture of the bond. The intermetallic formation rate at the interface is diffusion-driven and is a function of time, temperature and alloying element [6]. Satisfactory mechanical properties can be achieved by reducing the thickness of intermetallic compound layer [7]. The thickness of intermetallic compound layer can be reduced by controlling the process parameters and composition of weld metal [2], controlling the heat flow into weld [8] and by using an interlayer which exhibits improved diffusion resistance to both Al and Fe [9,10].

The techniques available for joining the dissimilar incompatible metal combinations are generally limited to the processes which do not result in the melting and solidification of metals to be joined [11—16]. Among the various solid-state welding processes currently available, the friction welding is probably the most proven and established welding technique. The material combination (high strength low alloy steel and aluminium) is reported to be welded by solid-state processes [9,15,17] and, to a limited extent, by friction welding without interlayer [18].

The present work is aimed at studying the effect of silver in the form of electroplating as interlayer to produce the joint between low alloy steel and aluminium alloy and to understand the role of silver in preventing the formation of brittle intermetallics. The joints were characterized through optical microscopy, scanning electron microscopy (SEM), X-ray diffraction (XRD), scanning electron probe microanalysis (SEPMA), and the mechanical properties were evaluated in terms of microhardness and tensile strength.

2. Experimental procedure

Aluminium alloy AA6061 in T6 condition and low alloy steel AISI 4340 in quenched and tempered condition in the form of 16 mm diameter rods were used for friction welding. Friction welding was carried out on a continuous drive friction welding machine with friction force of 3 kN, upsetting force of 6 kN, rotational speed of 2400 RPM, and burn-off length of 2 mm. Friction welding parameters were selected based on the optimization studies carried out earlier on joining of dissimilar metal combinations [19]. It was recommended that the incompatible materials should be welded at low burn-off length (length loss during friction stage of welding). Low burn-off length results in lower heat input and consequently less time availability for formation of intermetallics. Silver was electroplated on the faying surface of AISI 4340 using standard commercial technique by subcontracted plating firm. The detailed electroplating procedures are not given because they are confidential to the various electroplating firms. A 20 μm-thick silver was electroplated on AISI 4340 since it does not undergo deformation as compared to AA6061. Fig. 1 shows the friction welded joints obtained with AA6061 and AISI 4340 without interlayer and with silver interlayer.

The weld specimens were sectioned and metallographically polished. The specimens were etched with Keller's reagent for AA6061 side and with Nital solution for AISI 4340. Tensile testing was performed employing standard specimen configuration confirming to ASTM standard E8-04, having gauge length of 25 mm with weld interface located at the centre of the specimen. Tensile test specimen used for testing is shown along with its dimensions in Fig. 2. Tensile tests were performed on an Instron 1185 universal testing machine. The cross head speed during the tensile test was maintained at 1 mm/min. Three tensile test specimens were tested and the average of the tensile test results are reported. The failed tensile specimens were subjected to fractographic examination using LEO scanning electron microscope.

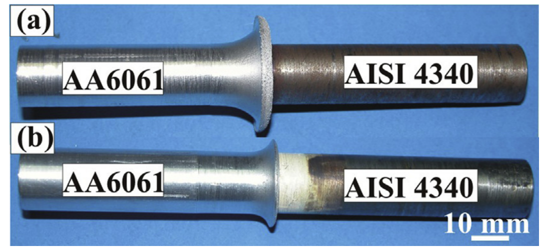

Fig. 1. Macrograph of friction welded AA6061-AISI 4340 (a) without silver interlayer and(b) with silver interlayer.

Quantitative analysis and X-ray mapping was carried out to know the elemental distribution across the weld interface by scanning electron probe microanalysis (SEPMA). Quantitative analysis was carried out at an interval of 2 μm. The welds were subjected to X-ray diffraction by employing Philips PHL 3020 X-ray diffracto-meter using copper K_α radiation for the identification of various phases. Micro Vickers hardness was measured across the interface of the weld using 100 gm load to determine nature of interface.

3. Results

3.1. Optical microscopy

Optical macrograph of a longitudinal section of welds made without interlayer is shown in Fig. 3. From the macrograph it may be observed that aluminium alloy (AA6061) is deformed extensively while no deformation could be noticed on the low alloy steel side during welding. The microstructure near the interface does not show any refinement of grains in steel. However, the aluminium resulted in fine grain structure near interface. The microstructures of the welds without and with interlayer are presented in Fig. 4. The weld interface is straight, a wide dark region is noted on the aluminium alloy beside the weld interface. The joints with silver as interlayer show the replacement of dark region with a bright region.

3.2. Scanning electron probe microanalysis (SEPMA)

The elemental X-ray mappings and quantitative analysis across the weld interface in the central region of weld without

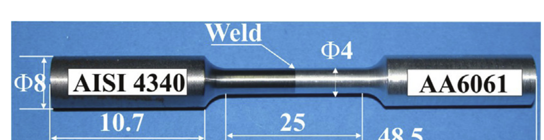

Fig. 2. Tensile test specimen with dimensions (all dimensions in mm).