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Temperature Effect on Non-Vacuum Solid State Diffusion Bonded Joints of Al 2014

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Abstract

Diffusion bonding is a joining process that relies on the inter-diffusion of atoms across the interface as the primary mechanism. Diffusion bonding techniques such as solid state and transient liquid phase (TLP) bonding are currently performed in a vacuum, which is a time-consuming, costly method and also limits the size of the components that can be bonded adequately. The present study aims at achieving the diffusion bonded joints of AA2014 under the bonding temperatures of 440, 460, and 480 0C. Microstructural evaluation is carried out using light optical microscopy (LOM), and scanning electron microscopy (SEM). Energy dispersive spectroscopy (EDS) is used for elemental analysis on the interface of the bonded specimens. Hardness at the interface is evaluated using the Vickers Microhardness test.

Keywords: *Inter-diffusion, solid state bonding, TLP bonding, interface, microstructure*

1.0 Introduction

Aluminium alloys are widely used as suitable materials for various engineering fields where weight to strength ratio is predominant. The Al 2014 alloy is a critical alloy used for army vehicles and aerospace applications [1]. The complex alloy system cannot be joined using conventional joining techniques, which rely on the melting and solidification phase of metal to generate a joint. The fusion welding process melts an alloy which affects the microstructure constituents, so to avoid microstructural changes over the joint region, a joining procedure that does not require melting or that uses a limited and controlled melting process must be adopted [2]. Diffusion bonding is a joining technique in which the welding of two similar or dissimilar metals can be joined with the application of pressure and heat for a specific interval of time [3]. The joint formed is free from any microstructural defects. Diffusion bonding is mainly classified into two types, solid-state diffusion bonding, and transient liquid phase diffusion bonding. Solid-state diffusion bonding can be performed through either a controlled atmosphere or vacuum [4,5]. Diffusion bonding in a vacuum is costly and the equipment is complex in construction, also the time required for the complete process is more compared to the diffusion bonding performed in the atmosphere, but the formation of oxidation is the main obstacle for air diffusion bonding [6]. The combined pressure and temperature (0.5-0.8 Tm) are used to establish a sound joint at the interface of the metals. In the diffusion bonding process, no larger deformation occurs within the metals being joined. Because the formation of the bond interface is entirely dependent on the combination of micro plastic deformation and the diffusion process [7]. Because there is no melting at the joint, any residual vacancies at the bonding interface are filled, and the parent metal

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microstructure is preserved across the bond interface [8]. Two major requirements must be met for diffusion bonding to be successful, first, the faying surfaces must be free from any oxides and adsorbed gases. Second, these surfaces must be brought together within interatomic distances in order for the bonds to form [9]. These requirements are rarely met in the solid state diffusion bonding of aluminium alloys in the air due to the robust oxide layers on the surface. These oxide layers act as an impediment to the bonding surfaces, by preventing interdiffusion. The oxide layer is extremely stable and has very limited solubility in the parent metal even at high temperatures. to overcome these issues, traditional diffusion bonding processes necessitate bonding surface preparation, and chemical cleaning [10-11].

Diffusion bonding of aluminum alloys in the atmosphere is a challenging task, as rapid oxide formation is always a hurdle. Electrodeposition of copper on aluminium surface is performed to reduce the oxidation [6]. Zinc cladding technology is also incorporated to inhibit oxide on aluminium surface and to improve the joint properties [12]. However, a solid state joint is necessary for some industrial applications where the intermetallic compounds are not suitable.

In the present study, solid state diffusion bonded joints of Al2014 are produced under different bonding temperatures with constant pressure and holding time. The effect of bonding temperature on the microstructure of the interface is analyzed.

2.0 Experimental Procedure

Al2014 (0.8Mg-0.5Si-0.30Fe-0.1Cr-3.9Cu-0.4Mn-0.15Ti-bal. Al, wt%) is employed as the parent material. The specimens are cut into 50 mm x 50 mm x 5 mm using a wire-cut electrical discharging machine (EDM). The faying surfaces were ground on P400, 600, 800, 1000, 1200 grit SiC paper and by the diamond suspension. Oxide layers are eliminated on the joining surfaces by chemically cleaning the specimens with 6%NaOH+ 40% HNO_3. Then the specimens are ultrasonically cleaned in acetone for 10 min before the diffusion bonding process. Solid-state diffusion bonding is performed in a customized furnace attached to a universal testing machine (UTM) under the temperature condition of 440, 460, and 480ºC with a heating rate of 6ºC/min. The bonding pressure of 15 MPa and holding period of 45 min are kept constant. The solid-state bonding process carried out on a UTM with a customized heating chamber is schematically shown in Fig.1.

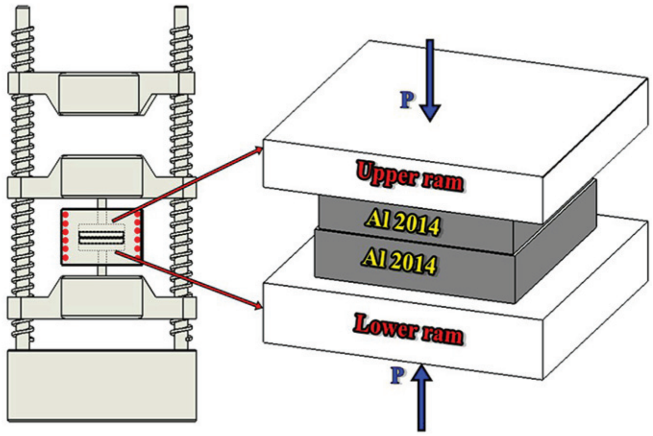

Figure 1: Schematic representation of diffusion bonding process on a UTM

The specimens bonded are cooled to room temperature in the furnace to avoid thermal shocks. Then the specimens are sectioned perpendicularly to the joint and ground and polished and treated with Keller's reagent (etchant). Microstructure at the interface and the base metal surface is examined through SEM. Elemental distribution is observed using EDS. The Microhardness test is conducted using a Vickers microhardness test rig with an indentation load of 200 gm and a dwell time of 15 sec.

3.0 Results and Discussion

3.1 Temperature effect on joint formation

Initial microstructural observation is made using LOM. Fig.2 shows the optical micrographs of the bonded sections at different bonding temperatures. The joint produced under the bonding temperature of 440ºC (Fig.2(a)) clearly shows a thick bonding line with continuous pores and cracks, as the bonding temperature increased to 460 0C the bonding line has become thin as shown in Fig.2(b). However, at 480ºC (Fig.2(c)) the bonded sections do not show any bonding line without any cracks and circular voids, and homogeneity of the base metal can be seen in the center area of the bonded sections.

SEM micrograph of the bonded section at 440ºC is shown in Fig.3(a), revealing that elliptical microvoids and cracks are present consistently together with the joint surface, indicating an incomplete bond. EDS analysis at point 1 indicates a high oxide content

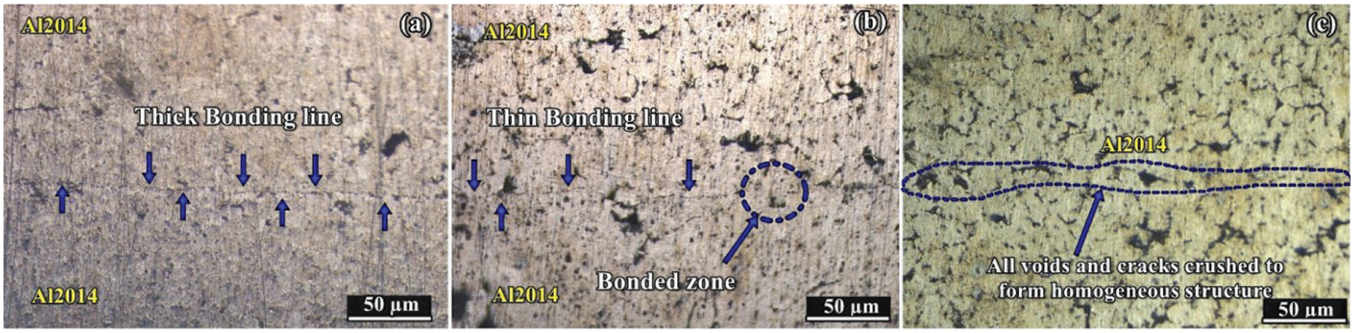

Figure 2: Optical micrographs of bonded sections at temperatures (a) 440°C (b) 460°C (c) 480°C

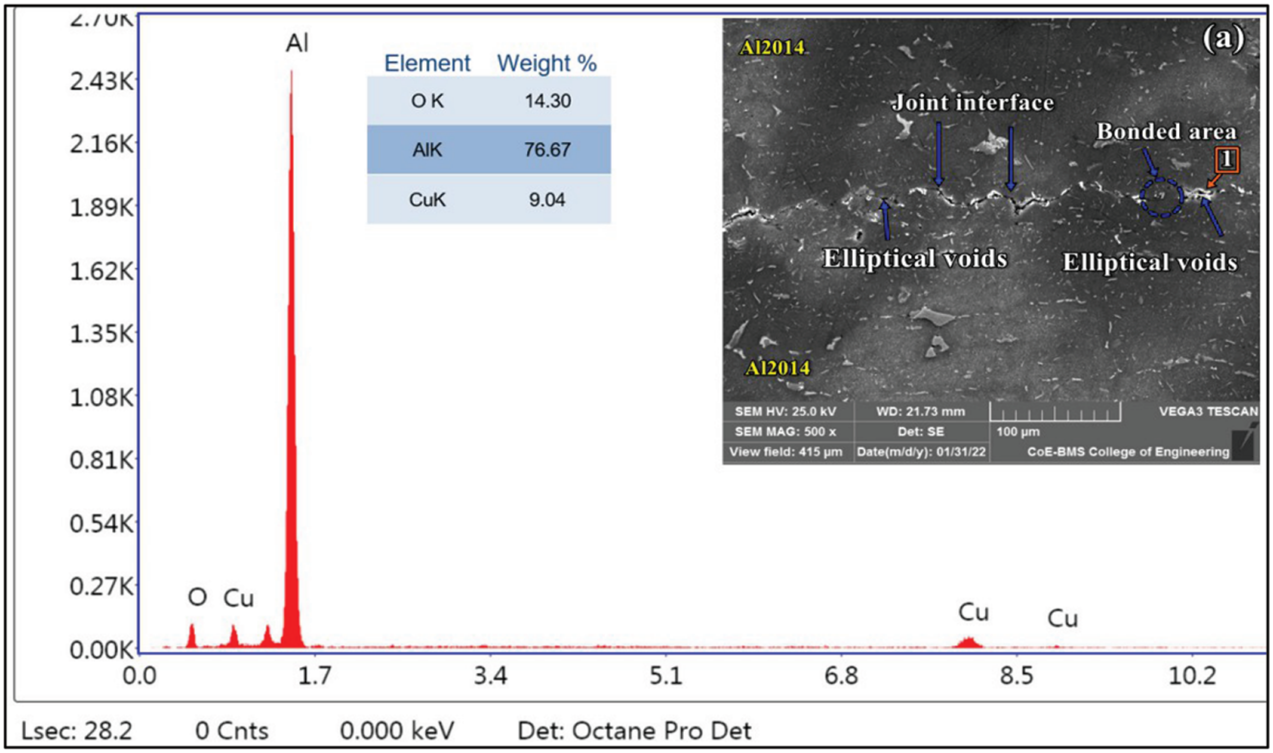

Figure 3: SEM micrograph and EDS analysis of joint interface bonded at temperature 440°C

although a partial bond occurred it is mainly because the bonding temperature is not sufficient to break the oxide layers completely.

When the bonding temperature is raised to 460°C, the voids were compressed to produce a barely visible bond line as shown in Fig.4(a), and also exhibit a grain development across the interface. The oxide layers are crushed by the higher temperature during the bonding process which is shown in EDS analysis at point 2 in Fig.1.3. The joints produced at 460°C also have a few smaller interfacial voids, which are observed intermittently in some regions.

However, when a bonding temperature is further increased to 480°C, minute spherical voids and the oxide layers are crushed to form a homogeneous microstructure [13], which is supported by EDS analysis at point 3 in Fig.5. The SEM micrograph shown in Fig.5(a) does not reveal any bonding line and metallurgical variations at the joint interface.

3.2 Microhardness at the Joint sections

Microhardness profiles at the joint interface of the sections bonded at temperatures 440, 460, and 480°C are shown in Fig.6. The joint made at 440°C exhibits lesser hardness values compared to the base material, due to the incomplete bond, as grain formation across

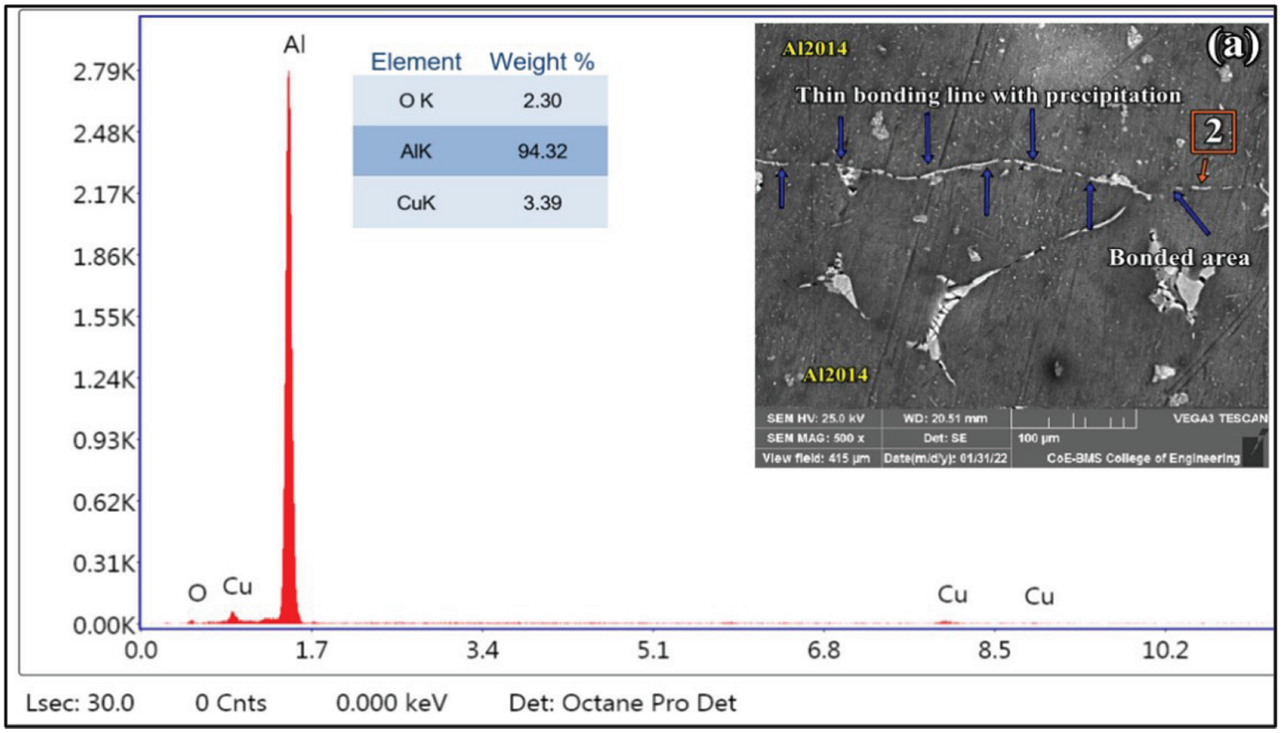

Figure 4: SEM micrograph and EDS analysis of joint interface bonded at temperature 460ºC

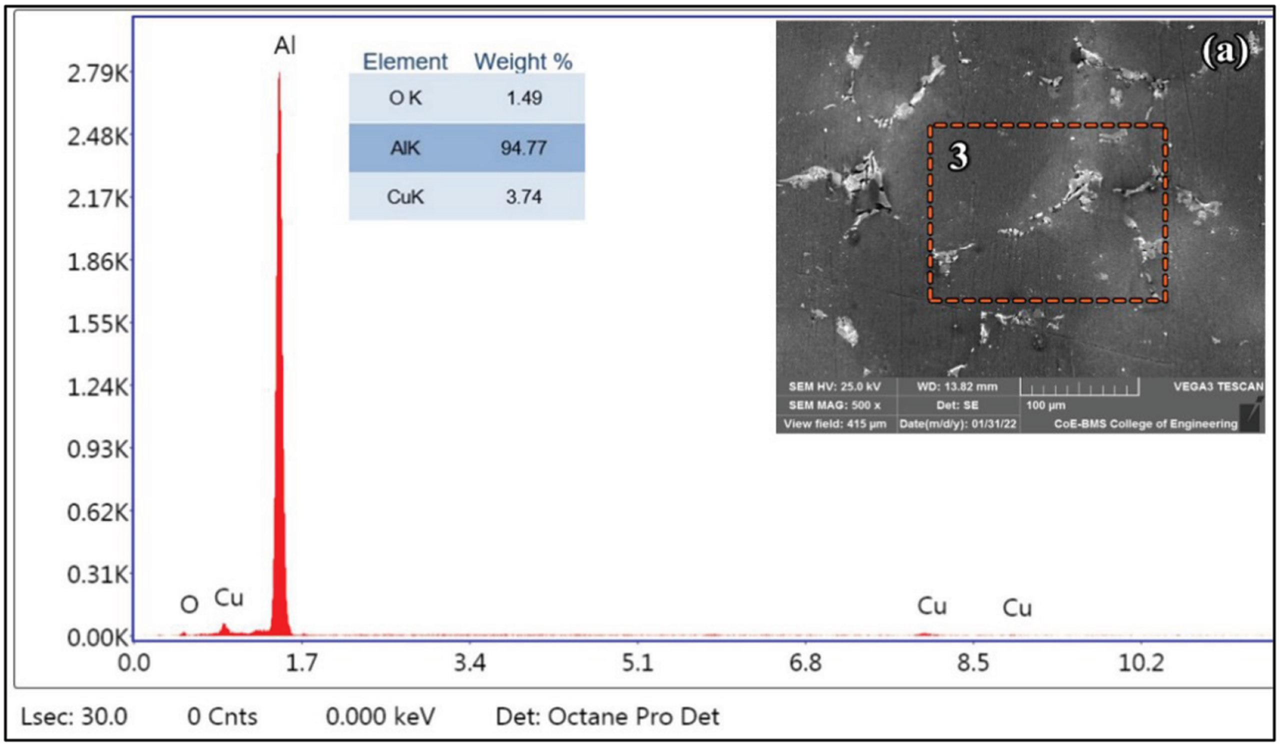

Figure 5: SEM micrograph and EDS analysis of joint interface bonded at temperature 480ºC

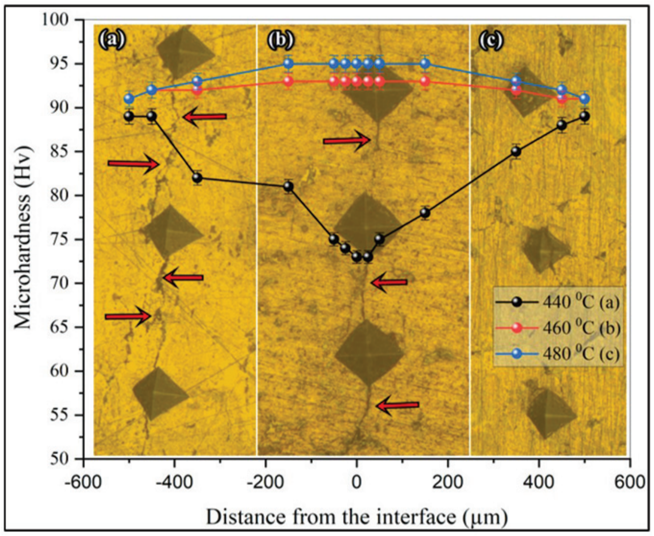

Figure 6: Microhardness profile for the joint sections bonded at 440, 460, and 480°C

the joint section does not occur. Whereas the hardness values at the joint interfaces made at 460 and 480°C are increased slightly but the values are approximately nearer to that of the base material [14-17]. The indentations on the bonding line for sections bonded at temperatures 440, 460 and 480°C are shown in Fig.6 (a), (b), and (c) respectively.

4.0 Conclusions

The non-vacuum diffusion bonding of Al2014 is carried out in atmospheric conditions and the effect of bonding temperature on the interfacial microstructure and hardness on joint interfaces are studied. The conclusions are summarised as follows,

1. Microstructural evaluation revealed that the grain formation across the joint has occurred and a homogeneous microstructure without evidence of any bonding line with the increase in bonding temperature.
2. The elliptical and spherical voids on the joint interface are eliminated and the oxide layers are crushed at a higher bonding temperature of 480°C.
3. The complete diffusion bonding at the joint interface is achieved at a bonding temperature of 480°C, holding pressure of 15 MPa, and bonding duration of 45 min.
4. Microhardness at the joint interface of sections bonded at 460 and 480°C exhibits approximately the same hardness values as that of base materials.

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