

Study of Microstructure and Mechanical Properties of Transient Liquid Phase bonded Al / Al₂O₃

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1- Introduction

Transient liquid phase (TLP) bonding is a relatively new bonding process that joins materials using an interlayer. When heating the interlayer, it will melt and the interlayer elements diffuse into the substrate materials, causing an isothermal solidification. The result of this process is a diffusion bond which has a higher melting point than the bonding temperature. A continuous thin layer of liquid may be formed at the joint interface through eutectic or peritectic reaction between the interlayer and the base metal. This reaction has the advantage of being able to remove the surface oxides. The liquid film wets the contact zone on the metallic substrates and solidifies isothermally, followed by the homogenization of the joint region. Hence, reinforced particles are incorporated into the bond region either by a particle-reinforced insert layer or melting back the substrate metal as a result of the eutectic reaction between the interlayer with the aluminum alloy. The composition of the interlayer can significantly affect the quality of the joints produced. Heating rate, interlayer composition and thickness have been reported as the most important parameters to reduce melt-back during TLP bonding in previous researches. These parameters also determine the width of the liquid phase, removal of surface oxide film, and particulate redistribution in the bonded region.

2- Experimental Procedure

Commercially pure aluminum sheets of 150×150×1 mm were used as base metal and Al₂O₃ powder with grain size of 20 μm was used as reinforcing component. Thereby, an Al-1100 alloy with grain size of 92 nm was produced by accumulative roll bonding (ARB) containing 5 wt-% of alumina (Al₂O₃) particles. Fig. 1 illustrates the homogenous dispersion of Al₂O₃ particles within the composite microstructure.

3- Results and Discussion

The effects of T_B on the microstructure of the joint areas are shown in Fig. 2 with the bonding temperatures ranging from 570 to 590 °C.

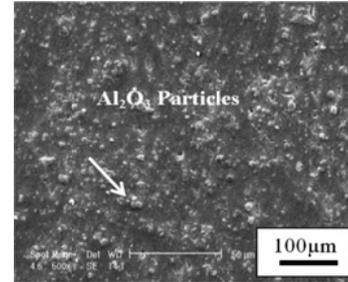


Figure 1 Microstructure of Al 1100/5 wt-%Al₂O₃ alloy

The microstructure of the bonding zone illustrated in Fig. 2a and 2b indicates that it contains homogenous particles by a sufficient inter-diffusion between the copper as an interlayer and aluminum nanostructured as a base metal. The bonding time of 20 min was not sufficient to complete the isothermal solidification of the melt. Increasing the duration time to 30 min was sufficient to complete the isothermal solidification. The final microstructure consisted of soft α-Al phase and micro particle of alumina, due to the absence of the brittle eutectic in the joint zone. An isothermal solidification was obtained for over 20 min at bonding temperature of 590 °C shown in Fig. 2c and 2d. Further increase in bonding temperature to 590 °C resulted in the elimination of micro-cracks and porosity of the interface and widening of the segregated zone as shown in Fig. 2.

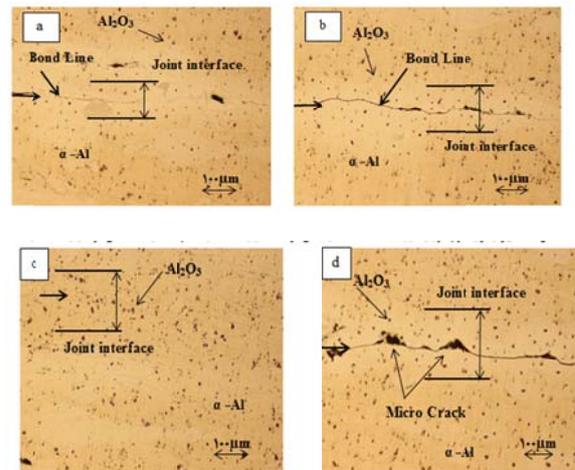


Figure 2 Optical micrographs of joint microstructure at bonding temperature of a) 570 °C for 20 min; b) 570 °C for 30 min; c) 590 °C for 20 min; d) 590 °C for 30 min

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X-ray diffraction analysis of the polished cross-section of a bonded interface made at 590 °C gives a

significant amount of alumina particles and intermetallic compounds within the joint zone as indicated by Fig. 3.

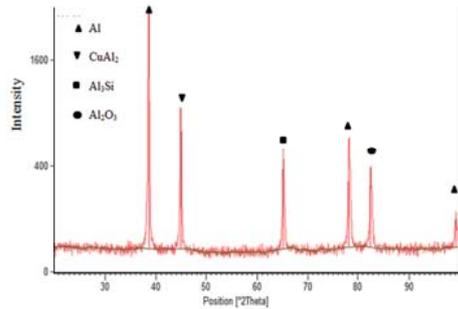


Figure 3 X-ray diffraction analysis of bonded fractured surface made at 590°C for 30 min

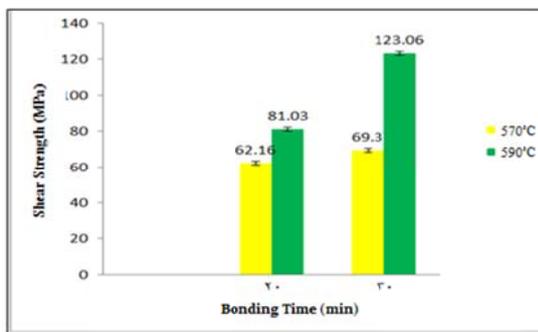


Figure 4 Effects of bonding time and temperature on joint shear strength

Fig. 4 shows that the shear strength increases with the holding time because of an increased homogenous bonding zone and higher interfacial bonding strength between the base material and bonding zone. An increase in bonding time to 30 min leads to the formation of a metallurgical bond by isothermal solidification. The results indicate a high concentration of intermetallic compounds such as CuAl₂ and Al₂O₃ at the fractured surface as indicated by Fig. 4. The increase in strength was attributed to the presence of micro-sized Al₂O₃ particles and reduced amount of brittle copper aluminide phases within the joint region.

To determine the cause of failure the fractured surfaces were examined using SEM. It was found for a bonding temperature of 570 °C, partially ductile and shear dimples were seen with many alumina particles visible on the surface and a ductile–brittle mixed mode of failure. Fig. 6 shows the hardness profile as a function of distance from the joint center in samples bonded at 570 °C and 590 °C for 20 min.

The hardness changes uniformly, is scattered around the joint region and does not follow a pattern. The microstructure of the bonded interface shows porosity, micro-cracks and the precipitation of hard

intermetallic compounds. When the bonding temperature was increased the average hardness value was observed to increase and the hardness value was highest in the joint center and decreased with increasing distance from the edge of the bonding zone into the base metal. The fluctuation in hardness value within the joint zone was attributed to the random distribution of ceramic particles within the soft aluminum matrix.

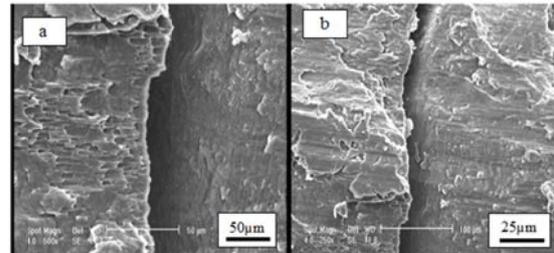


Figure 5 SEM images of joint fractured surfaces bonded at a) 570 °C; b) 590 °C

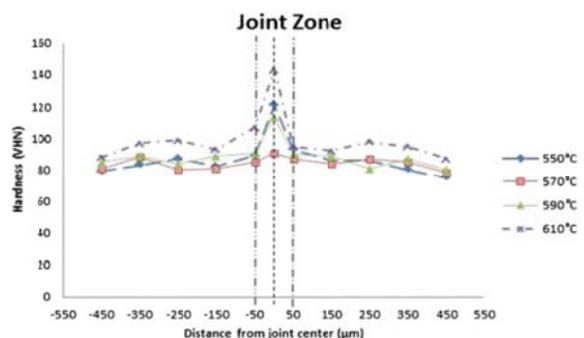


Figure 6 Temperature effects on joint micro-hardness across the joint

4- Conclusions

The nanostructure of the base metal was very effective to achieve the short time isothermal solidification in TLP bonding. It was found that raising the bonding temperature up to 590 °C benefits both the composition uniformity and interface bonding, resulting in strong joints and improved strength up to 123 MPa equal to 82% of the base metal average strengths. The results indicate that alumina reinforcements microparticles increase the joint strength and shorten the bonding time required to achieve a good joint strength. Analysis of the fractured surfaces showed plastic deformation, shear dimples and partially ductile failure with many alumina particles visible on the fractured surface. At low bonding temperature (570 °C), joint strength increases directly by holding time, whilst at high temperatures (610 °C), it has a decrease due to reduction of CuAl₂ particles in the α-Al solid phase.