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Characterization of Joints Produced by Diffusion Bonding

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Abstract

The present study reports on the preparation of diffusion joint of Al 2024 sheets with and without hematite interlayer. Parameters like holding time, temperature and pressure were considered for producing the joint. Samples were prepared at a temperature of 400 °C while varying load (90 and 110 kN). The time duration of applying load was selected as 25 and 35 min. Microstructural characterization using scanning electron microscopy was carried out for analyzing microstructure of the joint. EDS spectrum was used to analyze the elemental composition of the joint. Hardness tests were employed to find the micro-hardness of the prepared joint using Vickers hardness tester.

Keywords: *Diffusion Bonding, Interlayer, Micro-hardness*

1. Introduction

During recent years a variety of composites (Boppana *et al.* 2020; Aravinda *et al.* 2021; Boppana *et al.* 2021) have been prepared using quite a few methods (Dayanand *et al.* 2019; Bharath *et al.* 2020; Nagaral *et al.* 2021; Kumar *et al.* 2021) for numerous applications. Metals and alloys have to be joined in certain specific applications. Several techniques have been used to join materials. Diffusion bonding method involves joining dissimilar and similar materials. When components of metal are to be joined, they are subjected to microscopic deformation and hence the region at the joint is homogeneous. Some of the advantages of the solid-state joining process would be the ability to achieve high quality joints in which discontinuities related to metallurgical conditions do not form. If appropriate parameters are used during the joining process, the joint can be produced that has ductility and strength in same proportion as that of the parent material. Pressure, temperature and time play an important role during the process of diffusion bonding. It is also dependent upon the properties of the materials to be joined (Derby and Wallach, 1982). Researchers (Esposito *et al.*, 1998) worked on hot pressing method to join alumina ceramics using Cu, Ni and Fe as interlayers. Various phenomenon like creep, diffusion and evaporation act during the process of diffusion.Using a copper-based interlayer, steel metals and titanium were successfully joined (Elrefaey and Tillmann, 2009). They reported that a temperature of around 850 °C was used to join the dissimilar materials effectively. The researchers could prevent the formation of Fe and Ti intermetallics by the addition of Cu based interlayer. Diffusion bonded joints are able to retain the properties of material since they are not subjected to any changes in microstructure. Lightweight aluminium based alloys are considered for automotive, aerospace and military structure building application (Yan *et al.*, 2008; Chellman and Langenbeck, 1992). Solid

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state diffusion bonding process produces joints involving two flat interfaces at an elevated temperature using specific pressure/time dependent on the material to be joined. Carrying out diffusion bonding process in air is very challenging mainly due to formationof aluminium oxide (Lee *et al.*, 1999). Aluminium oxide layer acts as a hurdle in joining the two material surfaces and it's difficult to dissolve the stable oxide layer in the base metal by diffusion bonding process (Kazakov, 2013). The presence of film oxide layer reduces the bond strength significantly and in turn limits the application of diffusion bonding process. In order to avoid the formation of oxide layers, techniques incorporating usage of vacuum, in situ surfaces treatment, and implementing interlayers in between the joints is followed by few researchers. (Lee *et al.*, 1999; Kenevisi *et al.*, 2013; Urena *et al.*, 2000; Li *et al.*, 2007; Zhang *et al.*, 1999; Peng *et al.*, 2005; Jiangwei *et al.*, 2002; Torun *et al.*, 2008; Akca and Gursel, 2017; Kurgan, 2014; Yan *et al.*, 2004). In order to widen applications of diffusion bonding in the areas such as spacecraft, aerospace, military, structural panels and automotive sector, further, it is required to develop suitable and reliable joining techniques (Lee, 2012; Dunford and Wisbey, 1993; Han *et al.*, 2007). Diffusion bonding has the potential of joining similar/dissimilar metal without degrading the properties of their materials. At present, most of the diffusion bonding is done in vacuum which is more expensive as well as time consuming process. An ideal joint is prepared in the research work involving diffusion bonding of Al 2024 sheet with the help of a die that has the facility to control temperature during the process.

2. Experimental Set-up and Procedure

2.1 Material

The alloy of Al 2024-T0 having a thickness of 1.6 mm was used in the present study along with hematite ore powder as interlayer (size: 45μm). The samples with interlayers are prepared by adding 2 % weight fraction of hematite ore.

2.2 Experimental Set Up and Work

The customized die was used in a compression testing machine (Model CTM-2000 kN Datacone) for preparing the diffusion bonding samples in open air with various process conditions. Heat was supplied to the specimen kept in between the die through the temperature control unit as illustrated in Figure 1. The dies which were used in diffusion bonding process were made up of tool steel in which heating coils were inserted inside the die to generate heat.

The specimens were prepared with the size of 25.4 x 12.7 mm in a diffusion bonding unit under different loads and holding times by keeping the temperature constant at 400°C. After the diffusion bonding process, specimens were allowed to cool until it reaches the room temperature. The samples prepared for the test with different conditions are tabulated in Table 1. The process parameters for diffusion bonding are selected based on literature survey, study result and trial run results. The temperature recommended for diffusion bonding process range is 400°C. In the present study, 25 and 35 min were selected based on trial run; load of 90 and 110 kN was selected as per the trail run carried out on specimen. The specimens which are to be diffusion bonded are kept between the dies in lap joint configuration. The temperature is then increased until it reaches 400°C. The temperature is allowed to stabilize; gradually load is applied with the help of a compression testing machine for the fixed time period. The specimens are prepared with and without interlayers. Load is applied on the specified joint area considered in lap joint configuration. Polishing was carried out on the surfaces to be joined to get rough surface that might aid in joining process. In order to remove foreign particles, acetone and ethanol was applied to remove any of the contaminants present. Analysis of bonded joints were carried out through Scanning Electron Microscopy (SEM). Hardness properties of the bonded joint were also analyzed through micro hardness tester.

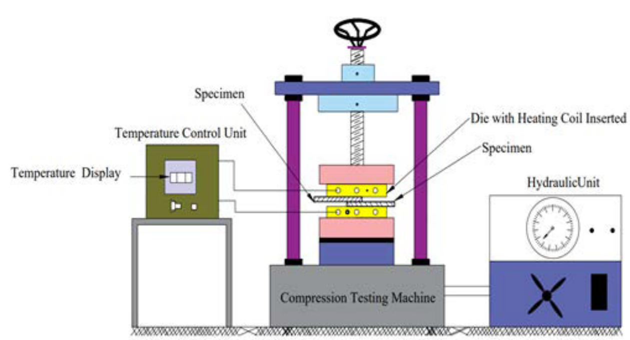

Figure 1. Diffusion bonding set-up.

3. Results and Discussion

3.1 Microstructural Analysis

SEM micrographs are used to analyze the diffusion bonded joint at interface zone. Samples were analyzed at the joint by keeping the orientation perpendicular to the diffusion bonded joint axis. SEM images of joints with and without interlayer (S1, S2, S3 and S4 as in Table 1) are shown in Figure 2 (a), (b), (c) and (d). In Figure 2 (a) for the sample S1 a discontinuous bond with cavities and oxide layer at the interface of bonded joint is observed. In Figure 2 (b) for the sample S2, a continuous bond with fine voids and oxide layer here and there is observed. In Figure 2 (c) for the sample S3, voids with oxide layer and non-continuous bond at interface are exhibited. Figure 2 (d) for the sample S4 with interlayer shows continuous bond with fine voids here and there along with oxide layer at the joints. As per the above observation, it can be concluded that, with increase in load, diffusivity increases which in turn increases the bond strength.Energy Dispersive Spectroscopy (EDS) analysis are carried out at the interface of bonded joint. EDS was used to find the composition of the joint prepared. Figure 3 represents the spectrum containing major elements in the sheet considered. It is observed that no new intermetallics are formed during the diffusion process.

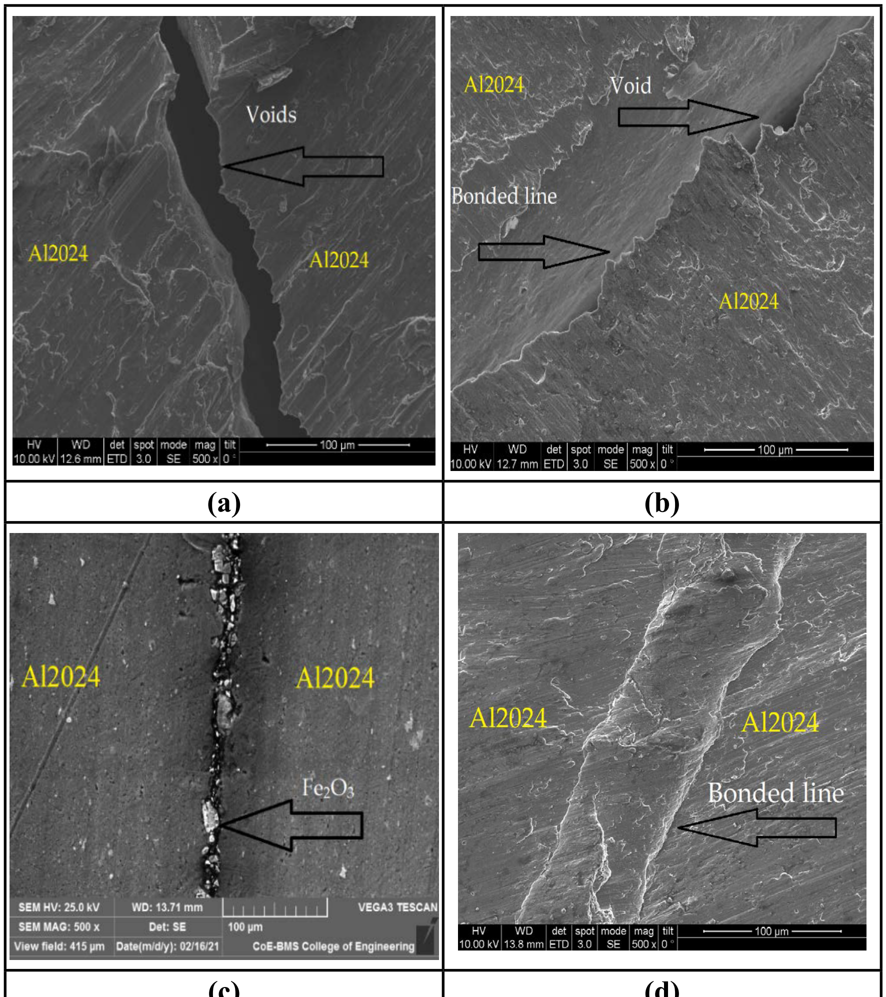

Figure 2. Shows the diffusion bonding at various conditions: (a) 400°C, 90 KN, 25 min/without interlayer (b) 400°C, 110 KN, 35 min/without interlayer (c) 400°C, 90 KN, 25 min/with interlayer (d) 400°C, 110 KN, 35 min/with interlayer

Table 1. Various parameters used to bond Al 2024-T0 with and without interlayer

Specimen Name	Process Parameters °C/ KN/ min	Interlayer
S1	400, 90, 25	None
S2	400, 110,35	None
S3	400, 90, 25	Fe_2O_3
S4	400,110, 35	Fe_2O_3

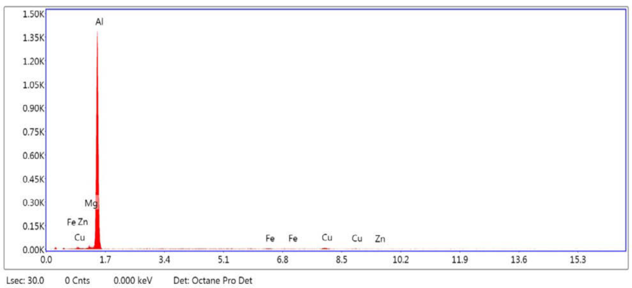

Figure 3. EDS of the joint.

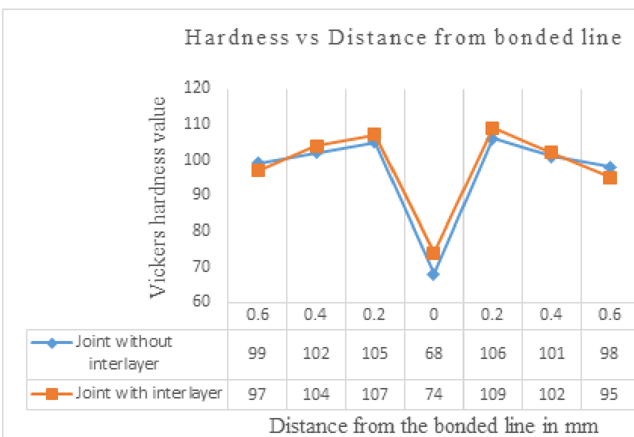

Figure 4. Vickers micro-hardness value vs. Distance from the bonded line.

4. Micro-hardness Testing

The Vickers hardness test was carried out on the bonded samples S2 and S4 since the bonding was found to be satisfactory from Figure 2. The hardness values were measured at the joint area at various points located on either sides of the mid line of the joint at distances of 0.2, 0.4 and 0.6 mm. The graphical plot representation of the hardness value distribution from the interlayer on either side of base metals are presented in Figure 4. The specimens are subjected to a load of 100 g with the dwell period of 10 sec. The micro-hardness test points on specimen were taken at 0.2, 0.4 and 0.6 mm on the either side of the joints. The specimen processed at 400°C, 110 kN and 35 min holding time with and without interlayer resulted in 74 VHN and 68 VHN respectively at the mid line of the bonded joint. Specimen prepared at a holding temperature of 400°C, revealed that the hardness value of the base material is higher when compared at interface joint. The hardness value of measurement revealed softening at the interface joint. The reason for lower hardness values may be attributed to the presence of voids at the interface region.

5. Conclusions

In the present study, the diffusion bonded joint involving Al 2024 sheets with and without using Fe_2O_3 was successfully obtained under various conditions. With increase in load, the diffusivity across the interface increases which in turn increases the strength of bond. The micro hardness test on joints were evaluated and results are summarized. The bonded joints assembly with interlayer showed higher hardness compared with bonded joints assembly without interlayer, which may be attributed to the existence of hard Fe_2O_3. The fusion of Fe_2O_3 as reinforcement to Al 2024-T0 at the interface increases the hardness value.

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