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# Characterization of Diffusion Bonded Aluminium Metal Matrix Composites (Al/Fly Ash MMC)

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## Abstract

In this study Aluminium alloy (AA6061) reinforced with Fly ash produced by stir casting process was diffusion bonded at constant pressure with various temperatures and time. Microstructure and Lap shear strength of the diffusion bonded joints were determined. Investigations show at bonding temperature of 475°C, bonding pressure of 10 MPa and bonding time of 30 minutes, exhibits high lap shear strength of 42 MPa.

**Keywords:** Aluminum alloy, Stir casting, Diffusion bonding, Shear strength, Microstructure.

## Introduction

In present usage of metal matrix composites is more because of their improved mechanical properties as high specific modulus, high strength to weight ratio, damping capacity and good wear resistance from unreinforced alloy. Aluminum Metal Matrix composites (AMC) used in many fields such as aerospace, automotive, defense and other fields for having excellent mechanical properties (1). Fly ash (FA) is the cheapest and low density reinforcement from the combustion of coal in thermal power plant (2). Aluminum Fly ash (AFA) decreases density and improved hardness, stiffness and wear resistance used in more potential applications, especially in engine parts and brake rotors (3). Stir casting is the simplest and cheapest method for preparing AFA composites, by mixing reinforcing particle into liquid metal by the casting process. The joining of the AMC is not successful in fusion welding because of uniform distribution of the reinforcement at the interface are the major problems. Diffusion bonding technique rectifies the problem and it joins many metallic and ceramic materials (4). Diffusion bonding is a solid state joining process and it provides to join similar and dissimilar metals. It develops a strong bond between the joint surfaces of the metal below the melting point. A diffusion bonding process controlled by three process parameters such as bonding temperature, bonding pressure and bonding time. These parameters are interrelated to each other. The bonding temperature should be 50% to 70% melting point of the metal (5-7). In the present work Diffusion bonding characteristics of AA6061 Aluminum alloy reinforced with fly ash (5%) have been evaluated.

## Experimental

*A. Test material*
AA6061-T6 Aluminum alloy used in this study, it was supplied from PMC Corporation Bangalore. Its chemical composition is presented in table

**Table 1:** Chemical Composition of AA6061 Aluminum Alloy By % Wt

| **Mg** | **Si** | **Fe** | **Mn** | **Cu** | **Ti** | **Cr** | **V** | **Al** |
|---|---|---|---|---|---|---|---|---|
| 0.9 | 0.68 | 0.18 | 0.03 | 0.22 | 0.01 | 0.09 | 0.01 | Bal |

The reinforcement used in this study was fly ash (1-100μm) and its' chemical composition are presented in table 2

**Table 2:** Chemical Composition of Fly Ash By % Wt

| **$SiO_2$** | **$Al_2O_3$** | **CuO** | **$K_2O$** | **CaO** | **MgO** | **$TiO_2$** | **FeO** |
|---|---|---|---|---|---|---|---|
| 51.4 | 29.65 | 4.86 | 1.57 | 2.87 | 1.72 | 2.54 | 5.39 |

*B. Composite preparations*
During processing of AFA, the fly ash (5 wt. %) was preheated at 850°C for 2 hours for removing the moisture. The Aluminum rods charged (1000 g) in the graphite crucible heated in the electric furnace (Fig.1) and maintain uniform temperature of 800°C (above the liquid temperature) hexachloro ethane tablets are charged into the furnace for degassing. The molten metal was permitted to cool (720°C slightly below the liquid temperature) to a semi – solid state. At this stage fly ash mixture and 1 wt. % of magnesium (used as wetting agent) was added to the melt and manual stirring was done for 10 minutes, after manual stirring the composite slurry reheated,to maintain 800°C and it has stirred by mechanical stirrer at 350 rpm for 7 minutes. The argon gas applied near the crucible during stirring to avoid the formation of an oxide

layer at the molten mixture. Then the molten mixture was allowed to solidify in the preheated (300°C) square shaped die (100 mm X 100 mm X 10 mm)


**Figure 1:** Stir Casting Furnace

*C. Sample preparation Diffusion bonding technique*

The fabricated AFA composites were machined to square shaped specimen 45mm X 45mm X 8mm. All the specimens were polished to mirror appearance by metallographic polishing process. The polished specimens were cleaned with acetone. The polished specimens were placed in a die set up and the entire diffusion bonding setup was placed the vacuum chamber (vacuum pressure of $10^{-3}$ mm of Hg was maintained).

**Figure 2:** Diffusion Bonding Machine

Diffusion bonding machine setup is shown in Fig.2.The specimens were heated by the induction furnace at the heating rate of 25°C/min up to the required bonding temperature at the same time required bonding pressure was applied by a servo controlled hydraulic press. After the specimens were bonded, the specimens were cooled to the room temperature before removed from the furnace. From the above procedure 18 specimens were fabricated as mentioned in the process parameter table.3.Some of the diffusion bonded specimens shown in Fig.3.

**Table 3:** Diffusion Bonding Process Parameters In This Study

| Bonding Temperature (℃) | Bonding Pressure (MPa) | Bonding Time (min) | Lap shear strength (MPa) | Diffusion layer thickness (μm) |
|---|---|---|---|---|
| 450 | 10 | 45 | 28 | 4.505 |
| 475 | 10 | 30 | 42 | 13.514 |
| 500 | 10 | 20 | 30 | 5.405 |

**Figure 3:** Diffusion Bonded Samples

*D. Microstructure analysis and Lap shear test*

Microstructure was measured at different interface region by light optical microscope (Make: Meltzer optical instrument Pvt. Limited, India).The above bonded joints were not enough standard test size for measuring lap shear test.Hence a non-standard test was carried out to measure the shear strength of the bonds. Lap shear test specimen diagram is shown in Fig.4. Tests were carried out in 5 ton capacity servo controlled Universal testing machine (Make: FIE –Blustar, India).

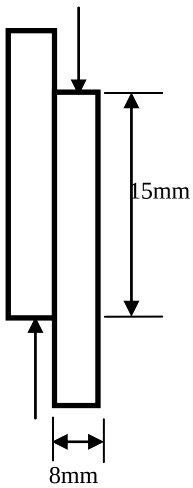


**Figure 4:** Lap Shear Test Specimen Diagram

## Result and Discussion

*A. Microstructure analysis*

Optical microstructure was taken in the bonded region and used to know the influences of the process parameter for the development of diffusion layer are shown in Fig.5 (a,b,c).Diffusion layer formation depends on the dislocation of atoms between the metal surface to join the metal surface and it forms intermetallic compounds. The above observations are in agreement with Fick's second law. Distributions of particle at the intermetallic compounds not affect the joint performance. It improves the joint strength. Intermetallic compounds not joined the whole body and it's also not affects the mechanical properties of the metal surface as strength and plasticity. Strength and plasticity decrease when the diffusion layer thickness below 5µm (6-8). In Fig.5 (a), the bonding temperature of 450℃ diffusion layer thickness is found to be low (4.505µm) because of insufficient bonding parameters. In Fig.5 (b) the bonding temperature of 475℃ diffusion layer thickness is high (13.514 µm) because of optimum bonding parameters. Fig.5 (c) the bonding temperature of 500℃ diffusion layer thickness is low (5.405µm) because of excessive bonding parameters.

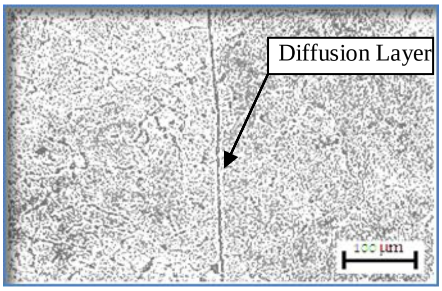


**Figure 5 (a)**

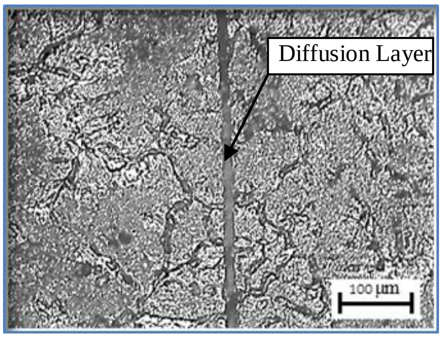


**Figure 5 (b)**

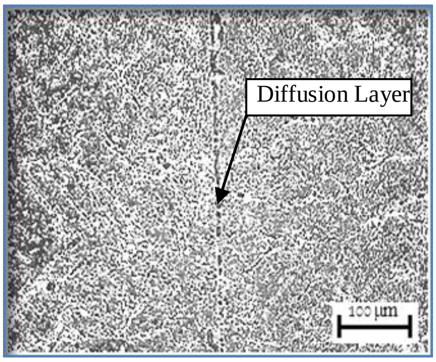


**Figure 5 (C)**

**Figure 5:** Optical micrographs at various bonding temperature

*B. Lap shear strength*

By increasing bonding temperature, surface conditions are changed and improving yielding stress from the Fig.6. Lap shear strength is increasing with the increase in temperature (6-9). At 450°C the lap shear strength of the bonded joints is low (28 Mpa), because of poor contact between the bonded surface. At this temperature ability of flow of atoms between the bonded surfaces is low. When increase the bonding temperature to 475°C lap shear strength improves considerably (42MPa) because of higher contact and high diffusivity rate of atoms at the bonded surface. A further rise in temperature of 500°C causes reduction of lap shear strength (30Mpa). Increase in temperature increases the fluidity of atoms and at the same time by applying the pressure (10MPa) reduces the diffusion layer thickness and thereby reduces the lap shear strength. From this report, it is apparently known lap shear strength of the joints depends on temperature, pressure and time. The Shear strength of the joints was increased with increase in temperature and then decreases. The actual requirement of shear strength of aircraft structure is 10 -20Mpa (6-9). Hence, in this analysis, shear strength values of all bonds fulfill the above requirement and makes good bonding. From the above analysis, diffusion bonding temperature of 450°C and 500°C has lower diffusion layer thickness and strength. But the bonding temperature of 475°C has higher diffusion layer thickness and strength. From this analysis, it was found the diffusion layer thickness direct relationship between the lap shear strength

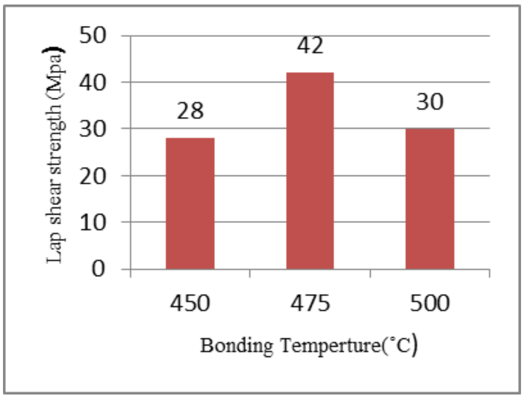


**Figure 6:** Lap Shear Strength At Various Bonding Temperature

## Conclusion

The strength of diffusion bonded joints to be examined in detail through lap shear strength and microstructure analysis. Diffusion layer thickness plays an important role. Diffusion bonding process parameters such as 475℃ of Bonding temperature, 10 MPa of Bonding pressure and 30 minutes of bonding time to produce maximum shear strength 42 MPa.

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