Impact of Diffusion Bonding Parameters on Bonded Joints of Al2219-Cu Alloy for the Application of Heat Sink Device

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***Abstract*— This study investigates the effects of diffusion bonding parameters on the microstructural and mechanical properties of bonded joints of Al2219-Cu alloy, aimed at optimizing its performance for heat sink device applications. The influence of bonding temperature, pressure, and time on the joint's microstructure, tensile strength, and thermal conductivity was systematically examined. The results show that optimal bonding parameters can significantly enhance the joint's properties, leading to improved thermal management and mechanical reliability. The findings of this research provide valuable insights into the diffusion bonding process and its application in the development of high-performance heat sink devices.**

Keywords— Diffusion Bonding; Characterization, Temperature; Pressure; Time

The increasing demand for high-performance electronic devices has driven the need for advanced thermal management systems [1]. Heat sink devices, which are critical components of these systems, require materials with high thermal conductivity, mechanical strength, and reliability [2]. Aluminum alloys, particularly Al2219, have been widely used in heat sink applications due to their excellent thermal conductivity, corrosion resistance, and affordability [3]. However, the addition of copper (Cu) to Al2219 can further enhance its thermal conductivity and mechanical properties, making it an attractive material for high-performance heat sink devices [4].

Diffusion bonding, a solid-state welding process, has been increasingly used to join Al2219-Cu alloy due to its ability to produce high-quality joints with minimal distortion and residual stresses [5]. The process involves applying pressure and heat to the joint, allowing the atoms to diffuse across the interface, and forming a strong bond [6]. However, the quality of the bonded joint is highly dependent on the diffusion bonding parameters, including temperature, pressure, and time [7].

Optimizing the diffusion bonding parameters is crucial to achieve high-quality joints with excellent mechanical and thermal properties. Several studies have investigated the

effects of diffusion bonding parameters on the properties of Al alloys [8-10]. However, there is a lack of research on the specific effects of diffusion bonding parameters on the bonded joints of Al2219-Cu alloy for heat sink device applications.
This study aims to investigate the impact of diffusion bonding parameters on the microstructural and mechanical properties of bonded joints of Al2219-Cu alloy. The effects of bonding temperature, pressure, and time on the joint's microstructure, tensile strength, and thermal conductivity will be systematically examined. The findings of this research will provide valuable insights into the diffusion bonding process and its application in the development of high-performance heat sink devices.

I. EXPERIMENTAL PROCEDURE

Aluminum alloy 2219 (Cu-6.48, Si-0.49, Fe-0.23, Mn-0.32, Mg-0.01, Zr-0.2, V-0.08, Ti-0.06, Zn-0.18, Al-Bal wt %)
And copper (Cu-99.990, Si-0.001 wt%) are utilized in this work.The specimens are polished by SiC sheets of different sizes of range (220-1000).After this using chemically cleaning the materials with 6% NaOH and 40% HNO3, oxide coatings on the faying surfaces are removed then the bonding specimens are cleaned in acetone for 10 mins. Figure 1 shows a schematic representation of the bonding furnace, base metals in an arrangement and specimens are then kept in the vacuum bonding furnace in a stacked manner.

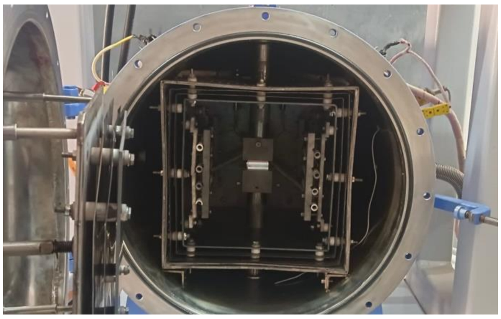


Figure 1. Specimens in Vacuum chamber

Figure 2. Vacuum Bonding Machine

The diffusion welding is conducted at a constant temperature of 510 °C bonding pressure of 1, 1.75, 2.5MPa for holding times of 75 minutes. The bonding temperature was selected in the temperature range over the eutectic temperature and below the melting point of Aluminum and using previous studies [11]. The diffusion welding method needs longer holding time than other solid-state welding methods to ensure intimate contact, improve joint quality, void closure and improve grain growth across the interface [12]. To prevent thermal shocks, the specimens that are being bonded are cooled to room temperature in the furnace. Following diffusion welding, the samples are cut perpendicularly to the welding joint using wire EDM to evaluate microstructure and shear strength. The specimens are subsequently polished with a range of SiC grit papers (220-2000) and refined using a 1µ diamond suspension. The polished samples are then ultrasonically cleaned in an acetone bath and dried with hot air In the present examination Scanning Electron Microscope TESCAN-VEGA3LMU equipment is used, its specification are as follows; resolution of 3nm at 30kv, magnification of 4.5xto1000000x with tungsten heated cathode, scanning speed of 20 ns to 10ms per pixel adjustable in steps or continuously, image size up to 8, 192 pixels in 32-bit quality. The prepared samples were tested for the following specifications. The SEM images results are discussed in the upcoming chapters. The hardness measurements across the joint section are tested using a Vickers microhardness test rig (MICRO-MACH) with an indentation load of 50 g and a dwell period of 15s. Joint strength is evaluated by shear test (BISS-25 kN) with a loading rate of 1mm/min at room temperature conditions.

III.RESULTS AND DISCUSSON

The binary phase of Al-Cu shown in Fig.4, predicts the formation of CuAl2 (θ), Cu Al (η), Cu4Al3 (ζ), Cu3Al2 (δ), and Cu9Al4 (γ). Lee et al. reported the difficulty in finding Cu3Al2 (ζ) and Cu3Al2 (δ) phases, anticipating that the short bonding time generates thin, unclear reaction layers that may have intermixed with different IMC. Initially, the CuAl2 phase is observed at the interface between the aluminum and copper, as the maximum solubility of Cu in Al is 2.48 at%, whereas that of Al in Cu is 19.7 at%. Hence, Al the IMC reaction layers formed on the bonded sections as observed in Fig 4. Delamination and micro voids are seen between the layers of the bonded specimens of sample 1 (Fig.4 (a)) at 1 MPa, which may be owing to insufficient pressure applied for complete plastic deformation of the IMC layers or inadequate bonding time provided for maximum nucleation of the CuAl2 phase. In the EDS pt.no. 2 we can observe 81.19 wt. % of aluminium and 18.821 wt. % of copper in the delaminated reaction layer this speculating the formation of Cu9Al4.As bonding pressure is increased further to 1.75 MPa, a decreased reaction layer is observed showing that closure phenomenon of delamination and voids is not completely done. A light grey reaction has been formed as observed in Fig 4 (b). It has 69.94 wt. % of Al and 30.06 wt. % of Cu, which can be predicted as α-Al+CuAl2 phase. As bonding pressure is increased further to 2.5 MPa, continuous and thick reactions layer (Fig.4 (c)) of height 21 µm is formed. It has a range of around of 72 wt. % of aluminium and 27 wt. % of copper, predicting the CuAl2+CuAl phase in it. Hence we can say that bonding pressure has an impact on the void closure phenomenon. High pressure increases the bonding area, grain boundary recrystallization and grain enlargement. Atoms diffuse into the copper readily, leaving vacancies on the aluminum side, and the copper- rich atoms, which have lower diffusivity, occupy these vacancies created on the Al side. All the bonded specimens show various IMC reaction layers as shown in

Fig.4 with varying concentrations of Cu & Al elements. We have carried out EDS analysis to investigate the varying composition of elements at different IMC reaction layers this is shown in Fig.6 BSE images of diffusion bonded Samples at (a) 1 MPa (b) 1.75 MPa (c) 2.5 MPa

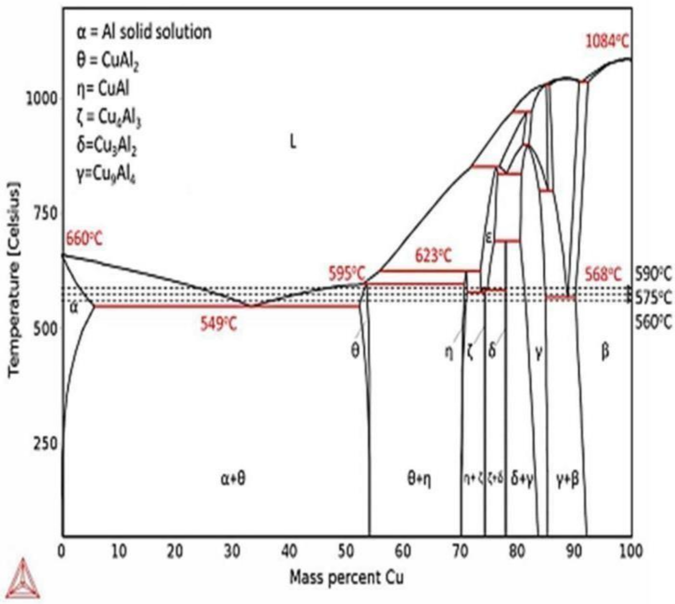
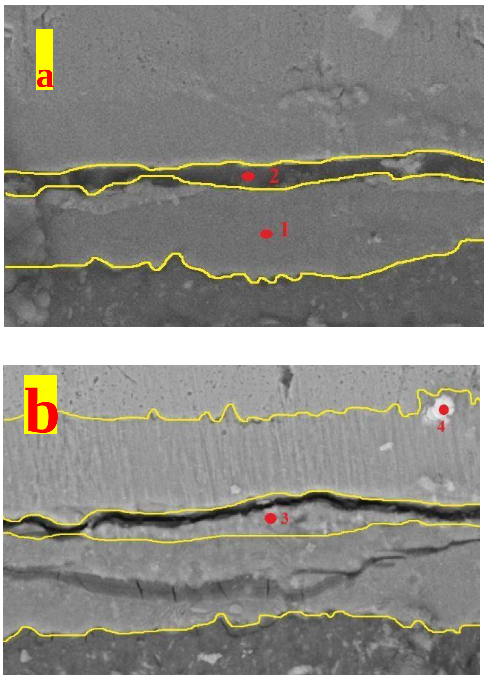


Figure 3. Binary phase diagram of calculated Al-Cu



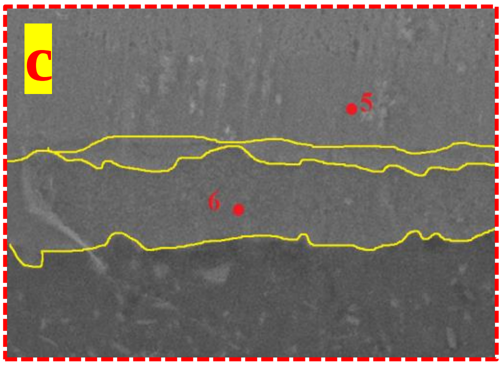
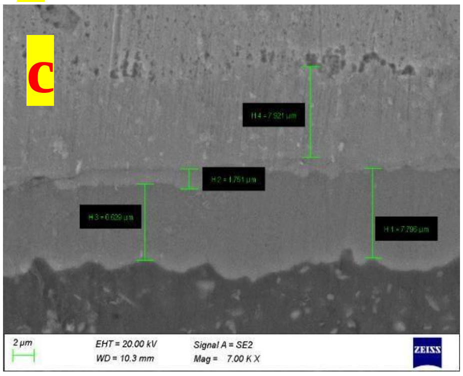


Figure. 4 Magnified view of the area marked in Fig. 4.1 (a), (b) and (c)

EDS Points	Aluminium Atomic %	Copper Atomic %	Probable Phases
1	65.15	34.85	**α-Al+CuAl2**
2	81.19	18.81	**Al2Cu**
3	45.06	54.94	**Cu4Al3+Cu3Al2**
4	69.94	30.06	**α-Al+CuAl2**
5	55.01	44.99	**CuAl2+CuAFl**
6	36.31	63.69	**Cu9Al4**

Table 1 Composition of elements as observed in EDS

The surface interaction between Copper & Al2219 is caused by inter diffusion of atoms and kinetics in addition to the thermodynamic force Table 1 shows the summarized point EDS results for different reaction layers, and the respective EDS spectrograph c



a

b

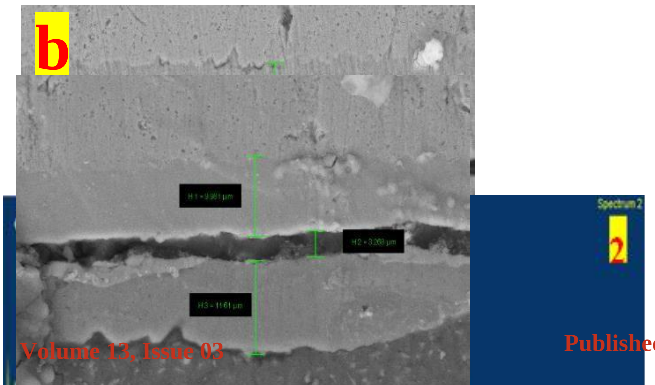


Figure.5 EDS spectrographs of the points marked in Fig. 4.2 (a), (b), and (c)

Sufficient atomic migration and complete metallurgical bond can be obtained by having appropriate parameter combination levels among bonding time, temperature and applied pressure. The established reaction layer within the Al/Cu joint is divided into three regions. Region A is the reaction area/segment adjacent to the Al substrate while region C is the closest region to the Cu substrate. Evidence of lateral delamination is observed to occur at the interfacial regions of sample 1 .This shows that shear stresses are high in these bonded areas causing to the applied low pressure causing delamination. Then, at an adequate Pressure, and under melting temperature of aluminium, a eutectic reaction between Al2219 and copper occurs, in which

The EDS analyses of the identified regions were carried out to ascertain their exact compositions. The EDS spectrum of the points are shown in figure 5 .The increase in the thickness of the diffusion zone is mainly attributed to the improved inter diffusion with the increase in bonding pressure, and meanwhile, the thickness of the copper alloy is effectively reduced.

Figure. 6 BSE images of DB Samples at (a) 1 MPa (b) 1.75 MPa (c) 2.5 MPa

Fig. 7 shows Micro hardness characteristics of the bonded joints at pressures of 1, 1.75, and 2.5 MPa. The hardness values for the base metals of Al2219, Cu, and the diffusion zone were determined by averaging ten individual readings taken from different indentation locations. The Load is 50 gms and loading time is 15 secs. Further analysis observed an increase in hardness values at the diffusion zone where the IMC reaction layers are formed, which stipulates the presence of hard intermetallic beside the copper alloy. A maximum hardness of 75 Hv is observed on the Al2219 base metal, whereas on the copper alloy, it is 90 HV. The diffusion zone of the specimen bonded at 1 MPa has a hardness of 695 Hv, and the diffusion interface produced at 1.75 MPa increases it to 394 Hv. However, the sample that was subjected to a bonding pressure of 2.5 MPa shows a peak hardness of 710 Hv, and it may be said that with an increase in bonding pressure, hardness measurement of the diffusion zone in the joints increases. The variation in the different interfaces Hardness Values is caused by the brittle IMC phases formed at the interfaces.

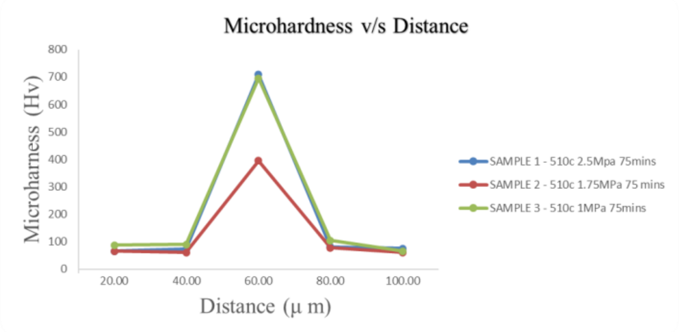


Figure 7 Graph showing the effect of pressure on micro hardness

Fig 8 illustrates the effect of bonding time on shear strength. The joint produced at 1 MPa exhibits 53 MPa of shear strength, caused due to voids, delamination along the bonding lone and insufficient bond quality. Furthermore, shear strength of 63 MPa, 86 MPa is observed at 1.75 MPa and 2.5 MPa, respectively. Here all the three samples used have a constant temperature of 510 c and holding time of 75 minutes. This is due formation of hard reaction layers in the IMC region which is found to be formed in sample 3 where there is a closure of interfacial cracks, voids.

Sample no.	Temperature (in °C)	Pressure (in MPa)	Time (in mins)	Shear Strength (in MPa)
1	510	2.5	75	85.92
2	510	1.75	75	63
3	510	1	75	53

Table 2 Pressure Effect on Shear Strength

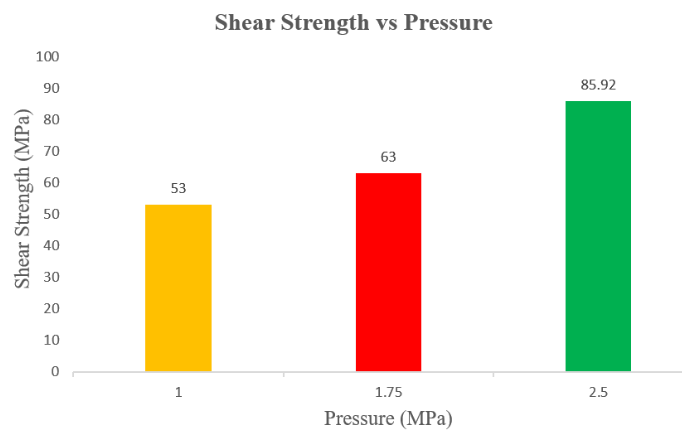


Fig 8 Graph showing the effect of pressure on Shear Strength

III.CONCLUSION

- Solid State diffusion bonded joints of Al2219 with a copper are successfully produced, and the intermetallic compounds formed across the diffusion joints are investigated over the pressure range of 1-2.5 MPa.
- All the bonded specimens exhibit various reaction layers at the bond interface of Al/Cu, and in addition, it is observed that the interface thickness of the bonding zone has increased with an increase in the bonding pressure.
- The diffusion thickness of 25, 23 and 21 μm are obtained for the boding pressure of 1, 1.75, and 2.5 MPa, respectively. With increase in pressure width of diffusion thickness reduced leading to better bonding strength.
- The hardness on the bonded interface sections increased with an increase in bonding pressure, and it reaches a maximum of 710 Hv on the diffusion zone side of the specimen bonded at 2.5 MPa.
- With the increase in bonding pressure, Shear Strength has increased and a maximum Shear Strength of 83 MPa found on the diffusion zone of the specimen bonded at 2.5 MPa.

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