Simulation of Transient Liquid Phase Bonding Process and the Influence of Interlayer Thickness

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Abstract. Ceramic/metal joints are possible with solid state joining techniques. Transient liquid phase bonding is a solid state joining process which is choice process. In this paper, numerical simulation of TLP bonding of ceramic/metal is done by Finite Element simulation. The finite element analysis of the TLP process provides the temperature and residual stress distribution during the bonding. Aluminium sheet as interlayer having high wettability is used. Transient thermal analysis is performed and discussed.

Keywords. TLP; Temperature Distribution; Transient Liquid Phase Bonding; Interlayer Thickness; Dissimilar Joints.

1. Introduction
In the present manufacturing scenario, the need for joining of dissimilar materials is drastically increasing and it can’t be ignored. Various conventional and unconventional joining processes are explored to find the joining possibility. Among them, transient liquid phase bonding is an effective process to join dissimilar materials with high integrity. The major drawback of the transient liquid phase bonding process is the thermal mismatch between the base materials. Transient Liquid Phase...
Bonding (TLPB) is applied to join materials of various combinations such as metal-metal, metal-ceramics and ceramics-ceramics, required in automotive and electronic industries [4,5].

The interlayer material is one of the important process parameter and it is placed between the base metals to be jointed [6-9]. The major consideration for the interlayer material is that it should possess a lower melting point than the substrate/base material. The whole specimen is placed in a furnace and heated to a temperature below the melting point of the substrate material and the assembly is held at the bonding temperature for a specific time period for isothermal solidification [10-13]. The resultant joint possesses a higher re-melting temperature than the initial melting temperature.

Friction stud welding [14-33], Friction Plug Welding [34-38], Diffusion bonding [39, 40], Friction Welding [41-55] Friction Drilling [56-67], and Friction Riveting [68-70] are few processes employed for joining of dissimilar metals. TLB technique overcomes most of the difficulties encountered by all these techniques. Arafin & Medraj (2006) said that the holding time decreases by increasing the bonding temperature & decreasing the interlayer thickness, using interlayers. Experimental work had good agreement with numerical simulation results generated through finite element based software [9].

2. Numerical Analysis

It is widely known that thermal mismatch is a major factor in determining joint mechanical behaviour because this may lead to the formation of residual stress at the bonded interfaces. These stresses are pre-induced on any stresses generated during subsequent thermal or mechanical loading, and thus strongly influence the strength of the joint. A three dimensional transient, isotropic solid with heat source finite element model was developed to simulate the transient liquid phase bonding process in Graphite/Copper using the commercial code ANSYS 15.0. As a first step in the analysis the transient temperature field $T$ which is a function of time $t$ and the spatial coordinates $(x, y, z)$, is solved. Modelling heat evolution between the coil and bonded sheet is an important step in understanding how it affects material flow within and surrounding the joint. To compensate for the lack of a predicted temperature field, measured temperature values from the literature [6] are used to construct an approximate temperature field for the TLPB process. This temperature field is then used as input for the structural model for the same TLPB process. As such, a problem geometry that accommodates the simulation of the preceding TLPB test is used.

| S.No | Material | Density Kg/m3 | Thermal Conductivity W/mK | Specific Heat J/Kg/K |
|------|----------|---------------|--------------------------|----------------------|
| 1    | Graphite | 2490          | 8.7                      | 771                  |
| 2    | Aluminium| 2700          | 173                      | 896                  |
| 3    | Copper   | 8960          | 398                      | 384.56               |

2.1. Assumptions
- The ambient temperature was assumed to be 20°C.
- Only thermal loading is applied.
- Bonding Temperature is kept constant as 700°C.
- Thickness of the interlayer is varied as 0.1mm, 0.2mm and 0.3mm
- Uniform cooling and dissimilar materials are perfectly bonded at the interface. The properties of Graphite, Aluminium and Copper are presented in table 1.
2.2. Material Modelling

The sheets of Graphite and Copper having dimensions of 0.015m*0.015m*0.06m is modelled. The Aluminium foil having dimensions of 0.015m*0.015m*0.001m issued as interlayer for the Graphite/Copper joint. Aluminium metal is taken as interlayer due to its high wettability and also it has a melting point of 660°C, which is lower than the melting point of the base materials. Figure 1 shows the modelled geometry and Table 1 gives the properties of materials.

SOLID70 which is a three-dimensional thermal solid is used as the element type for thermal analysis. SOLID70 has a three dimensional thermal conduction capability. The element possess eight nodes with a single degree of freedom and temperature, at each node. The element is applicable to a three dimensional, steady-state, or for transient thermal analysis. The element also can compensate for mass transport and heat flow from a constant velocity field. If the model which has a conducting solid element is also to be analyzed structurally, that element must be replaced by an equivalent structural element such as SOLID185. A free surface of the element (that is, not adjacent to another element and not subjected to a boundary constraint) is assumed to be adiabatic. Thermal transients having a fine integration time step and a severe thermal gradient at the surface will also be requiring a fine mesh at the surface. This element is not having the mass transport or fluid flow options.

SOLID185 Structural Solid is suitable for modelling general 3-D solid structures. It allows for prism, tetrahedral, and pyramid degenerations when used in irregular regions. Various element technologies such as B-bar, uniformly reduced integration, and enhanced strains are supported. Figure (2) shows the meshes generated for the present simulation. The shape of the mesh element is hexahedral shape. The meshes are composed of a total number of 2230 nodes and 10640 solid elements.The boundary conditions applied are convection coefficient of 1.33W/m2k around the surface of the plate and surface load of 901W/m2around the interface.

As the model is a symmetric geometry, it possess isotropic property. The mapped mesh is used to mesh the model. The fine mesh is obtained. The meshed model is shown in Figure 2.

3. Results and Discussion

The above numerical simulation is carried out to determine the temperature distribution of TLP joint for 700°C bonding temperature under various interlayer thickness as 0.1mm, 0.2mm and 0.3mm. The
result obtained shows that a high level of temperature distribution is obtained at 0.3mm interlayer thickness for the bonding temperature of $700^\circ C$. Since the temperature distribution is high at 0.3mm interlayer thickness, the stress created at that point is more which affects the strength of the TLP joint. Therefore it is preferable to go for a bonding temperature of $700^\circ C$ for graphite/copper joint with aluminium interlayer of 0.1mm interlayer thickness to get higher joint strength. Figure 3 shows the temperature distribution for 0.1 mm thick aluminium interlayer at $700^\circ C$. The minimum temperature value 88.95$^\circ C$ is obtained at Graphite side. This is because of the low thermal conductivity of the graphite. As the temperature at the Graphite is very much less than the melting point of Graphite, the properties of Graphite is not affected in this process.

Similarly, Figure 4 and Figure 5 shows the temperature distribution for 0.2 mm and 0.3mm thick aluminium interlayer at $700^\circ C$. The minimum temperature value for those models are also obtained at Graphite side. At this point, the temperature at the copper side is nearly around 600$^\circ C$. This is because of the high thermal conductivity of the copper. As the temperature at the copper is nearly the Glass Transition Temperature of copper, the possibility of affecting the properties of copper is more. To avoid that a cooling system is provided at the copper side in this process.

Figure 3: Temp distribution at IT=0.1mm Interlayer Thickness

Figure 4: Temp distribution at IT=0.2mm Interlayer Thickness

Figure 5: Temp distribution at IT=0.3mm Interlayer Thickness
4. Conclusion

The major problem encountered during transient liquid phase bonding process is the thermal mismatch that occurs during bonding. The thermal mismatch is the melting point difference between graphite and copper. This defect can be reduced by introducing an interlayer of aluminium. The main consideration about the interlayer is that it should possess high wettability and a melting point lower than the base materials. When an interlayer had been introduced in between the specimen, joining had been successively achieved. Numerical investigation shows that the interlayer acts as an interface of joint for the two materials. Because of this tendency, thermal mismatch becomes minimum and hence thermal stress becomes minimum. It is observed that when 0.1 mm thick aluminium sheet is used as an interlayer, thermal mismatch is minimized. This could eventually reduce the residual stress and thereby increase the joint efficiency between graphite and copper joints.

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