NUMERICAL SIMULATION ON JOINING OF CERAMICS WITH METAL BY FRICTION WELDING TECHNIQUE*

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The joining of ceramic and metals can be done by different techniques such as ultrasonic joining, brazing, transient liquid phase diffusion bonding, and friction welding. Friction Welding is a solid state joining process that generates heat through mechanical friction between a moving workpiece and a stationary component. In this article, numerical simulation on thermal analysis of friction welded ceramic/metal joint has been carried out by using Finite Element Analysis (FEA) software. The finite element analysis helps in better understanding of the friction welding process of joining ceramics with metals and it is important to calculate temperature and stress fields during the welding process. Based on the obtained temperature distribution the graphs were plotted between the lengths of the joint corresponding to the temperatures. To increase the wettability, aluminium sheet was used as an interlayer. Hence, numerical simulation of friction welding process is done by varying the interlayer sheet thickness. Transient thermal analysis had been carried out for each cases and temperature distribution was studied. From the simulation studies, it is found that the increase in interlayer thickness reduces the heat affected zone and eventually improves the joint efficiency of alumina/aluminum alloy joints.

Keywords: friction welding; Alumina, AA 6063; interlayer, thermal analysis.

1. Introduction

Friction Welding is a solid state joining process that produces coalescence by harnessing the heat developed through controlled rubbing of the faying surfaces. The coalescence of materials is obtained through the combined effects of pressure and the relative motion of the two workpieces, heating the joint interface and inducing plastic deformation of the material. It is also a complicated metallurgical process accompanied by a set of physical phenomena such as frictional heat generation, plastic deformation, cooling of high-

temperature metal and solid state phase variation. The Friction Welding process produces the weld under the compressive force contact of one rotating and one stationary workpiece involving the direct conversion of mechanical energy to thermal energy at the interface of the workpieces. The material at the interface flows plastically and forms an upset and the thermo-mechanical behaviour at the interface is obviously critical to the quality of the welded joint. Metal/ceramic joints become more important because they combine the properties of metals (such as ductility, high electrical, thermal conductivity) and ceramics (such as high hardness, corrosion and wear resistance) [1, 2]. But the joining of metals and ceramics is difficult. This can be overcome by using inter-layers[3].

During friction welding the heat is highly concentrated at the interface, so as a result the weld has a very narrow heat-affected zone (HAZ) which limits the variations in mechanical properties of the base metal to a small region. This HAZ can be reduced by using interlayer as the heat will be transmitted along the plate thereby reducing the HAZ in the welded component[4].The objective of this paper is to determine the temperature distribution between the ceramic and metal by numerical analysis and also to investigate the effect of the inter-layer in the welding process.

2. Experimentation

The weld combination of alumina and aluminium 6063 alloy is friction welded. The geometry considered is 12 mm diameter and 45 mm length. The weld parameters considered by Noh et.al.[5], are friction pressure, forging pressure and rotational speed while the friction and forging time were also considered. The geometry considered is shown below. The step and thread are considered due to the availability of the machine.

Figure 1: Part to be held in pneumatic plunger

Figure 2: Part to be held in the chuck

During the ceramics-metal welding process the interlayer plays a significant role apart from the thermo-plastic deformation. The temperature at the interface is recorded with an IR thermocouple.

3. Thermal Modelling

The governing equation for the thermal model for the friction welding process is given as,

$$K \left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right] + G = \rho c \frac{\partial T}{\partial t} \quad (1)$$

where K is thermal conductivity, T is the temperature, G is the heat generation rate, c is the specific heat, ρ is the density, t is the time and x, y, z are spatial coordinates.

The ρ, c and K are functions of temperature, which is important for accurate for thermal modelling. Both T and G are functions of x, y, z and t . Friction welding process consists of the heat generation by friction between two workpieces q_f , and heating from irreversible plastic deformation f both workpieces q_p .

Heat generation rate G is given as

$$G = q_f + q_p \quad (2)$$

This study assumes that friction between both the workpieces follows Coulomb's friction law. The friction heat generation rate, q_f , can be formulated as

$$q_f = 2\pi R N \mu F_n \quad (3)$$

The heat generation rate due to plastic deformation, q_p is

$$q_p = \eta \sigma \varepsilon \quad (4)$$

Where, η is the inelastic heat friction, σ is the effective stress and ε is the plastic straining rate.

Alternatively, Friction heat generation can also be calculated using machine torque as given below

$$q_f = (2\pi N \tau / 60 A) * \eta \quad (5)$$

Where, τ is torque, A is cross section area and η is inelastic fraction.

4. Finite Element Analysis of Alumina – Aluminium Alloy

The numerical simulation of the process is considered as axis-symmetric. ANSYS finite element package was used for the analysis purpose. The transient thermal analysis was done to determine the temperature distribution on the welded parts. The heat loss due to radiation is ignored because it is so small. The temperature dependant material properties considered for the numerical analysis are shown below.

4.1. Numerical Simulation using ANSYS Software

The procedure for the numerical simulation is given below.

- The part is imported from Pro-E in IGES format.
- The analysis type is chosen as thermal.

- The element type is defined. The element type selected is thermal solid 8 node 70 element. This element type is selected because it suits the thermo-mechanical problems.
- The temperature dependant material properties are defined.
- The volumes are glued together by using glue command.
- The material properties are assigned to the respective parts.
- Meshing is done. The mesh created is fine mesh.
- The analysis type is chosen as Transient thermal analysis.
- Thermal load is applied in the form of heat flux which is determined previously.
- The load step is defined as 500.
- The problem is submitted to be solved.
- Once the solution is done the result can be obtained.

The model is semi-empirical as experimentally measured torque is used as input for the heat flux. The heat flux generated is calculated by using the formula derived above. The temperature dependant material properties are considered for the metal (Al 6063) and the ceramic (alumina). The temperature dependant material properties are tabulated below. The change in temperature in the parts is due to conduction, convection and radiation.

5. Results and Discussions

From the numerical simulation it is observed that the temperature is distributed along the plate. Because the heat is distributed in the plate the Heat Affected Zone (HAZ) in the friction welded component gets reduced. The interlayer is essential to form a good joint between alumina and the aluminium alloybecause it increases the wettability of ceramic surface. The joint strength depends on the interlayer thickness and the mechanical interlocking at the interface of the both sides.

Table 4: Temperature distribution in alumina – Al 6063 alloy weld without interlayer and with varied interlayer thickness

Figure 1 (a): Temperature distribution in the friction welded alumina – aluminium alloy without plate

Figure 2 (a): Temperature distribution in the friction welded alumina – aluminium alloy with 0.5 mm interlayer

Figure 2 (b): Temperature distribution in the friction welded alumina – aluminium alloy with 0.5 mm interlayer

Figure 3 (a): Temperature distribution in the friction welded alumina – aluminium alloy with 0.95 mm interlayer

Figure 3 (b): Temperature distribution in the friction welded alumina – aluminium alloy with 0.95 mm interlayer

Figure 4 (a): Temperature distribution in the friction welded alumina – aluminium alloy with 1.3 mm interlayer

Figure 4 (b): Temperature distribution in the friction welded alumina – aluminium alloy with 1.3 mm interlayer

Figure 1 shows broader heat affected zone, since the simulation has been carried out without interlayer. When interlayer is included in the analysis, the heat affected zone in the joint is minimized (Fig 2), since heat flow gets dissipated to the interlayer. Increase in interlayer thickness leads to still narrower heat affected zone. Similar trend is observed when interlayers with 0.5 mm, 0.95 mm and 1.3 mm thickness are used.

6. Conclusion

The biggest problem encountered during friction welding of alumina and Al alloy is the cracking of the alumina during bonding. This was attributed to thermal shock effects and also to high primary torque values. Both these effects can be reduced by judicious choice of the weld settings.

When an interlayer had been introduced in between the specimen, joining had been successively achieved.

Numerical investigation shows that the interlayer acts as a buffer to absorb excessive heat in the interfacial region. Because of this tendency, heat affected zone becomes narrower and thermal stress becomes minimum. It is observed that when 1.3 mm thick aluminium sheet is used as an interlayer, heat affected zone is minimized. This could eventually increase the joint efficiency between alumina and aluminium alloy joints.

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