



Numerical modeling and experimental investigation on plasma-assisted hybrid friction stir welding of dissimilar materials



D.K. Yaduwanshi, S. Bag^{*}, S. Pal

Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Guwahati 781039, Assam, India

ARTICLE INFO

Article history:

Received 21 September 2015

Received in revised form 4 December 2015

Accepted 9 December 2015

Available online 10 December 2015

Keywords:

Preheating

Plasma assisted FSW

Functionally graded material

Thermal analysis

Dissimilar joint

ABSTRACT

Plasma-assisted friction stir welding (P-FSW) is a solid state joining process that preheats the high melting temperature material ahead of FSW tool and enhances the material flow to improve the weld quality. Quantitative calculation by a sophisticated mathematical model of hybrid friction stir welding for dissimilar materials is a daunting task due to complex issues like mixed property in the weld zone, flow mixing action and solid state phase transformation. A 3D finite element based phenomenological model is developed to study various aspects of P-FSW between aluminum and copper. A dedicated heat generation model at various contact conditions between tool and workpiece, and a Gaussian distributed heat flux from plasma arc is used for the simulation. In weld zone, the impression of time-varying functionally graded material (FGM) is used for material behavior. The numerical model results are validated with experimental measurement of P-FSW in terms of time-temperature history and computed isotherm of nugget zone. Relatively better agreement shows the robustness of the developed numerical model. The reliability analysis of the model is performed at various welding conditions. The effect of preheating by plasma source is analyzed by microstructural phenomena.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Dissimilar joint between copper and aluminum gains significant attention in many emerging applications like power generation, petrochemical, nuclear, aerospace, transportation, and electronics industries that leads to the joining especially by friction stir welding (FSW) process [1–10]. Due to the difference in thermo-physical properties, the joining of dissimilar materials pretense more challenging task than joining of similar materials [2]. FSW is a promising technology for joining metals with very different physical properties with optimum combination of process parameters. The joining between different aluminum grades as well high conductive materials like aluminum and copper are mostly found in literatures [3–8]. For joining of dissimilar materials, the position and offset of FSW tool possess significant constraint that affects the type of inter-metallic compound and its distribution within the nugget zone [9–10]. Substantial increase in heat input due to variation of process parameters leads to diffusion of copper particles into aluminum. In effect, there may be increase in the intermetallic compositions and probability of formation the micro cracks [11]. In contrast, the heat input facilitates the plasticized state of two different materials and mainly attributed to the harder material (copper) for transport [12].

Introduction of additional heat source along with conventional FSW tool (principal process) to preheat relatively harder material is termed

as hybrid FSW process. In the present work, plasma-assisted FSW process (P-FSW) is developed that preheat the copper side up to 500 K with optimum location of plasma arc and less mechanical energy is delivered by the tool that converted into heat. Preheating temperature can make up the lost heat and improves the material flow during the FSW process [13]. Bang et al. [14] employed gas tungsten arc welding (GTAW) as a preheating source to join aluminum with titanium alloy where the elongation and joint strength increase significantly as compared to conventional FSW welds. With the attempt to extend the tool life and to improve the joint efficiency, several hybrid FSW techniques have been used to weld high melting point metallic materials [12–15].

The demand of a reliable mathematical model is ever increasing since the differential influence of process parameters are better explained by sophisticated numerical model of hybrid friction stir welding process [16–17]. Al-Badour et al. [18] developed thermo-mechanical model based on coupled Eulerian Lagrangian method to simulate the friction stir welding of dissimilar aluminum alloy. Researchers applied computational fluid dynamics method to analyze the heat transfer and material flow in FSW [19–21]. Nevertheless, all these models are concerned with conventional FSW process. The limited studies are observed in the literature on modeling of dissimilar joint by conventional FSW and hybrid FSW processes. Bang et al. [22] developed 3D numerical model to simulate temperature distribution and residual stress in GTAW assisted hybrid friction stir welding of dissimilar materials. Moving heat source along with frictional heat between the work specimens and tool surface is considered to calculate the heat input.

^{*} Corresponding author.

E-mail address: swarupbag@iitg.ernet.in (S. Bag).

However, the model does not deal with the effect of change in material properties in the weld zone due to stirring action of FSW tool to precisely analyze the heat transfer and material flow. The material property of the mixed zone in dissimilar joint is difficult to specify due to mixing of materials over time. In the weld zone, the material distribution resembles as a typical distribution model of functionally graded material (FGM) that is verified by several researchers [23–25]. However, all these studies are limited to conventional FSW process. Therefore, the objective of present work is to develop improved modeling approach using time varying functionally graded material model along with conjugate heat source for P-FSW process to reliably predict the temperature distribution for dissimilar material joint. Moreover, the literature lacks in-depth analysis on the variation of peak temperature, estimation of cooling rate and consequent effect on recrystallized grain structure for the development of P-FSW process for dissimilar materials.

In this study, a finite element based heat transfer model is developed to investigate the effect of external heating on temperature distribution and material flow during friction stir welding between copper and aluminum. Time dependent material model is incorporated based on FGM that change with respect to the motion of tool and mixing of material in the weld zone. The rate of growth of the FGM region is estimated from the rotational and forward speed of the tool. The mixing composition of FGM is decided by tool offset. The heat generation of FSW is estimated using contact condition between tool and the workpiece. The quantitative prediction by numerical model is compared with in-house developed P-FSW process for welding of copper and aluminum. Reliability in prediction shows the robustness of the developed numerical model.

2. Physical model of P-FSW process

P-FSW is an innovative solid state joining process that has great potential to produce effective and defect free joint of dissimilar materials. The different physical and mechanical properties between aluminum and copper contribute to the asymmetry in both heat generation and material flow during FSW. These drawbacks can be overcome by introducing additional local heating to preheat the copper side up to 500–600 K with optimum location of plasma touch. It promotes adequate material flow around the tool and reduces asymmetry in material flow during FSW [13,22,26]. The schematic representation of P-FSW for dissimilar materials is shown in Fig. 1.

A three-dimensional heat transfer model for P-FSW process is developed by introducing the following assumptions. The temperature

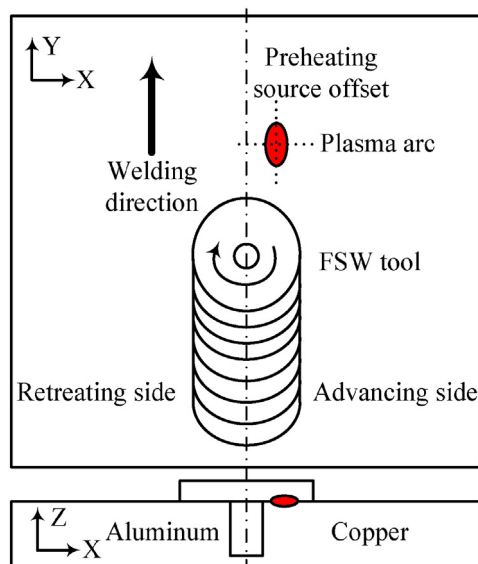


Fig. 1. Schematic diagram of plasma-assisted friction stir welding for dissimilar joint.

dependent thermal properties are considered during simulation. Linear Newtonian convective cooling is applicable to all five surfaces open to atmosphere. The materials are isotropic and homogeneous. The interface thermal resistance between two plates is neglected here.

The numerical model calculates the transient temperature fields within the solution geometry in which the interaction between tool, workpiece and backing plate are considered [27–28]. The temperature field (T) is estimated by solving three dimensional nonlinear heat conduction equation in which the tool moves in positive y -direction. The governing equation in a moving coordinate system is written as

$$\frac{\partial}{\partial x} \left\{ k_x \frac{\partial T}{\partial x} \right\} + \frac{\partial}{\partial y} \left\{ k_y \frac{\partial T}{\partial y} \right\} + \frac{\partial}{\partial z} \left\{ k_z \frac{\partial T}{\partial z} \right\} + \dot{Q} = \rho C_p \left(\frac{\partial T}{\partial t} - V_T \frac{\partial T}{\partial y} \right) \quad (1)$$

where ρ , C_p and k refer to density, specific heat and thermal conductivity of the workpiece material, respectively, $\dot{Q}$ is the rate of heat generation and V_T is the transverse speed of the tool. The heat generation in FSW is caused by friction and plastic deformation. The frictional heat is considered as a surface flux and included as boundary condition whereas heat generation due to plastic deformation is considered as volumetric heat ($\dot{Q}$). Boundary condition for FSW process is specified as surface interaction of the solution domain. The initial condition is expressed as

$$T(x, y, z, 0) = T_i \quad (2)$$

where T_i is the ambient temperature at time $t = 0$. The convection and radiation heat loss from the surfaces is mathematically expressed as

$$k \frac{\partial T}{\partial n} = h(T - T_0) + \epsilon \sigma (T_0^4 - T^4) - q_s - q_{pre} \quad (3)$$

where n is the normal direction vector of boundary, h is the convection coefficient, q_s is the heat flux at the interface between FSW tool and workpiece, ϵ is the emissivity, and σ is Stefan-Boltzmann constant. The last term of right hand side in Eq. (3) indicates heat input from external source in terms of surface flux.

2.1. Hybrid heat source for P-FSW

The heat source model is a combined effect of heat generation at tool surface and the surface heat flux from plasma arc. The additional heat source is basically a low power welding system where the primary heat source is due to friction and plastic deformation [28–30]. The frictional heat generation in FSW process is characterized by the contact condition at the interface and is described as sliding, sticking, or partial

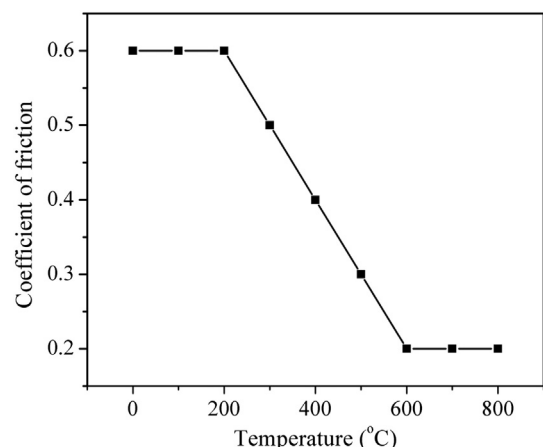


Fig. 2. Coefficient of friction as a function of temperature used in present simulation.

Download English Version:

<https://daneshyari.com/en/article/7218941>

Download Persian Version:

<https://daneshyari.com/article/7218941>

[Daneshyari.com](https://daneshyari.com)