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STUDY OF THERMO MECHANICAL CHARCTERISATION OF TOOL ON FRICTION STIR WELDING OF AA7075 AND AZ61

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Abstract

A numerical model is developed to predict the material deformations and temperature histories in the friction stir welding (FSW) process. Based on the numerical ananlysis, the effects of the welding parameters on material deformation and temperatures are investigated for plain cylindrical and drill tool geometries. Numerical results predicts that the temperature can be increased with the increase of the rotating speed on the FSW process. In the same way the increase in the weld speed can also lead to the tangible increase of the input power. When the rotating speed becomes higher, the welding speed must be increased simultaneously to avoid any possible welding defect. The model shows that the heat is generated on the regions of the shoulder, lateral surface of pin and tip of the pin. The predicted high temperature exists on the shoulder surface. The temperature varation is analysed for the three different tool geometries and base metals using ANSYS 14. The temperature field and predicted by the simulation method are in good agreement with the results obtained by the ANSYS 14. As per the deformation analysis during the first impact of pin the drill tool geometry obviously got more deformation and there by results in increment of total heat flux.

Keywords: Friction Stir Welding, heat generation, heat flux, deformation, Tool geometry.

Introduction

The friction stir welding (FSW) technique was invented by The Welding Institute (TWI) in 1991 [1]. Since then, the material flow mechanism during welding and the microstructures of the welds have been discussed vigorously. This new welding technology has been applied to aluminum products in various industrial fields, e.g.automobile and aircraft industries [2–5], due to the demands for lightweight parts and environmental protection. Friction stir welding is a relatively simple process as shown in Fig.1. Friction stir welding has a wide application potential in ship building, aerospace, automobile and other manufacturing industries. In the recent past, a few research activities have been developed on the numerical simulation of FSW processes. Thermal models, taking into account the heat generated by both friction forces work and the material deformation one, have been proposed [6–8] trying to highlight the temperature distributions nearby the rotating pin.

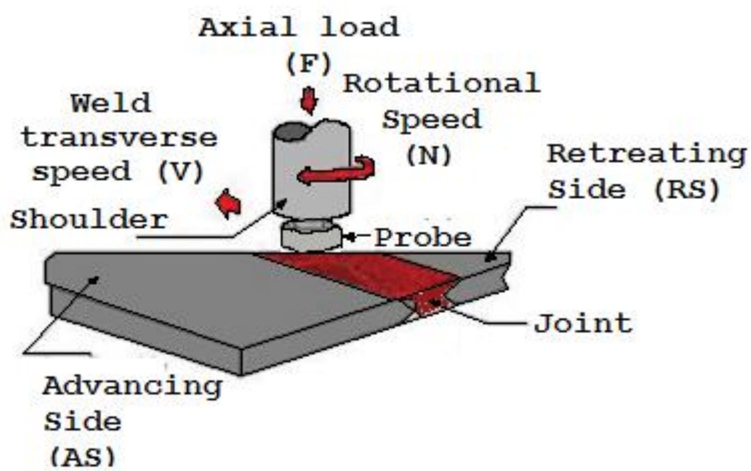


Figure 1 Schematic illustration of Friction Stir Welding.

Song and Kovacevic have modeled the heat transfer in FSW using the finite difference method [9,10]. Khandkar et al. [11,12] introduced a model of heat input based on the torque of the FSW tool that they then successfully utilized to model the temperature history of friction stir welded AA6061-T651 plate. Utilizing a three-dimensional visco-plastic model, Ulysee [13] studied the impact of varying weld parameters on the temperature distribution in an AA7050-T7451 plate. Frigaard et al. [14] developed a finite difference thermal model for a moving heat source and correlated the predicted temperature profile with the measured temperature profile for friction stir welded AA6082-T6 and AA7108-T79 extrusions.

The model developed by Chen and Kovacevic [15] uses the commercial FEM software ANSYS. A thermo-mechanically coupled Lagrangian finite element model, incorporating temperature and multi linear strain hardening, is used for the three-dimensional modeling of the solid structures. Gould and Feng [16] proposed a simple heat transfer model for predicting the temperature distribution in the workpiece of the FSW.

Midling [17], Russell and Sheercliff [18] investigated the effect of tool shoulder material and pin tool on heat input during the FSW. When modeling FSW temperature fields, it can be important to know the power of the heat source [19]. The heat transfer process during the tool penetration period cannot be modeled if the heat input from the pin is not included. Moreover, the initial field is very important in a transient heat transfer model, especially for modeling the preheat effects of laser-assisted preheated FSW[20].

Colegrave [21] uses an advanced analytical estimation of the heat generation for tools with a threaded tool pin to estimate the heat generation. Schmidt et al. [22] presented analytical equations for heat generation at the tool-workpiece interface and the heat generated by the pin taking sliding/sticking contact conditions into consideration. However, these literature studies is not correlated the thermal history analysis with deformation effect. This paper is concerned to develop the numerical model on heat generation of tool geomtry and the effect of heat flux due to the formation of deformation that is affetced during its initial kissing bond.

Numerical Modeling

It is obvious that experimental work without the knowldge of numerical analysis will be of costly. In accordance to literature survey, the heat generation plays a major role on the strength of Friction Stir Welded joint. In this paper, numeric model of heat generation is developed for cylindrical tool geometry and the correlated temperature distribution is also analysed with ANSYS 14.

In FSW process compared to the rotational speed, mechanical energy due to transverse movement is negligible with respect to the unit time and transverse movement is not considered. It is assumed on this anaytical model that the heat generation phenomenon does not include non-uniform distribution.

The heat generation on cylindical M2 probe is considered on the shoulder contact surface, side of the probe and tip of the probe.

The heat generation on the shoulder (Q_{Sh}):

$$Q_{Sh} = \int_0^{2\pi} \int_{R_p}^{R_s} \omega \, \tau_{condact} r^2 dr \, d\theta$$

$$= \frac{2}{3} \pi\omega \, \tau_{condact} \, (R_s^3 - R_p^3) \qquad \text{-----} \quad (1)$$

The heat generation on the side of the probe ($Q_{Side\ probe}$):

$Q_{probe-side} = \int_0^{2\pi} \int_0^{H_p} \omega\, \tau_{condact} r^2 dh\, d\theta$

$= 2\, \pi\omega\, \tau_{condact}\, R_P^2 H_P$ ----- (2)

The heat generation on the tip of the probe ($Q_{Side\ probe}$):

$Q_{probe-tip} = \int_0^{2\pi} \int_0^{R_p} \omega\, \tau_{condact} r^2 dr\, d\theta$

$= \frac{2}{3} \pi\omega\, \tau_{condact}\, R_P^3$ ----- (3)

These three heat generations are contributed to predict the total heat generation at contact surface.

$Q_{total} = \frac{2}{3} \pi\omega\, \tau_{condact}\, (R_S^3 + 3R_P^2 H_P)$ ----- (4)

The contact status is affected by sticking and sliding. The material flow mechanism is shearing the bonds of similar/dis-similar material and yields to rebond with each other. To accomodate the bonding the contact shear stress is assumed as follows

$\tau_{condact} = \tau_{yield} = \frac{\sigma_{yield}}{\sqrt{3}}$

The Q_{total} on equation (4) will be modified with this yield condition for the sticking condition on contact surface.

$Q_{total,sticking} = \frac{2}{3} \pi\omega\, \frac{\sigma_{yield}}{\sqrt{3}}\, (R_S^3 + 3R_P^2 H_P)$ ----- (5)

After the sticking condition, due to the translation of tool the contact surface is getting sliding condition. During sliding friction is developed on the contact surface, the Coulomb's friction law describes the shear stress.

$\tau_{condact} = \tau_{friction} = \mu\, P$

Thus for the sliding condition, the total heat generation is given by

$Q_{total,sliding} = \frac{2}{3} \pi\omega\ \mu\, P\, (R_S^3 + 3R_P^2 H_P)$ ----- (6)

This is counterbalanced by the additional plastic dissipation due to material deformation.

$Q_{total,FSW} = \delta\, Q_{total,sticking} + (1 - \delta)\, Q_{total,sliding}$

$= \frac{2}{3} \pi\omega\, (\delta\, \tau_{yield} + (1 - \delta) \mu\, P)\, (R_S^3 + 3R_P^2 H_P)$ ----- (7)

Where, δ - contact state variable (dimensionless slip rate)

τ_{yield} - yield shear stress at welding temperature

ω – angular rotation speed

The dimensionless slip rate varies between values 0 to 1.

When $\delta = 0$, sliding will occur and When $\delta = 1$, sticking will occur.

Heat generation ratio's are calculated for the cylindrical pin dimensions R_s = 9.5 mm, R_p = 4.5 mm, H_p =5.8 mm.

$$(H.G.R.)_{shoulder} = \frac{Q_{Sh}}{Q_{total}} = \frac{R_S^3 - R_P^3}{(R_S^3+3R_P^2 H_P)}$$

$$= 0.633$$

$$(H.G.R.)_{probe\text{-}side} = \frac{Q_{probe-side}}{Q_{total}} = \frac{3R_P^2 H_P}{(R_S^3+3R_P^2 H_P)}$$

$$= 0.2913$$

$$(H.G.R.)_{probe\text{-}tip} = \frac{Q_{probe-tip}}{Q_{total}} = \frac{R_P^3}{(R_S^3+3R_P^2 H_P)}$$

$$= 0.075$$

The M2 tool steel is taken as material for manufacturing the Friction Stir Weld(FSW) tool. S. Pereyra et al., analysed the various weld Parameters, developed a numerical model for heat transfer and material flow models. For the current analysis the convective heat transfer coefficient is assigned as 10 W/m^2 K as per his developed model[23].

According to Fig. it is found that the contact tempertures on Aluminium plates FSW are vaires from 300 to 430^0 C. This temperature variation account for the base metal and the current analysis deals with the tool temperture variation. The pin surface temperature is assigned as 200^0 C and shoulder temperature as 300^0 C.

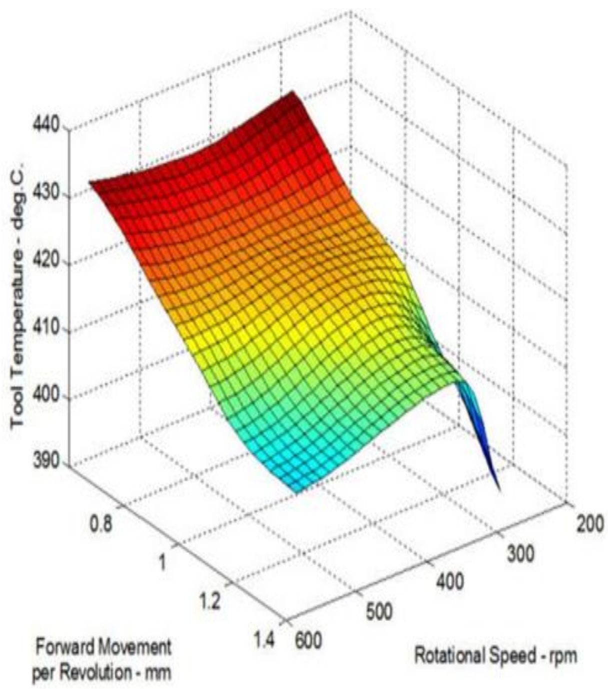
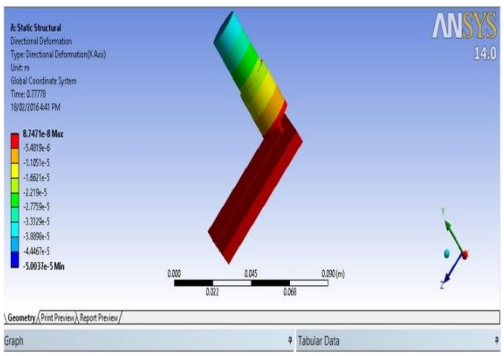
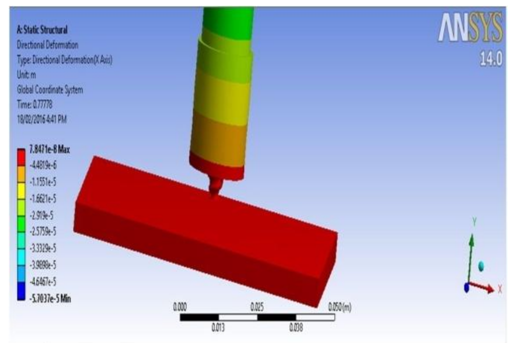


Figure-2. Model predicted tool temperature in a Friction Stir Welding tool during the welding of aerospace grade aluminium plates. Via the developed models the system can ‘map’ process conditions and internal process variables to the performance of the material. [24]

Figure 3 shows the comparision of maximum and minimum deformation by (a) cylindrical pin profile geometry and (b) drill tool profile geometry. It is evident that both pin profiles attains the maximum deformation on shoulder that in tends the maximum heat generation will be at shoulder. For drill pin profile the maximum deformation is comparatively low. So the temperature distribution on figure 4 (b), drill tool profile is considered only for kissing bond.



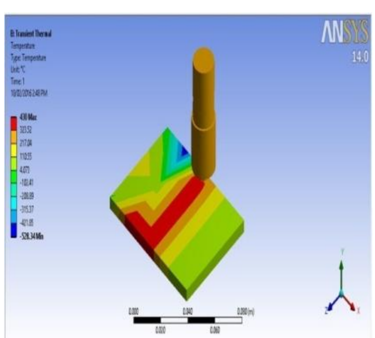
(a) Cylindrical pin profile



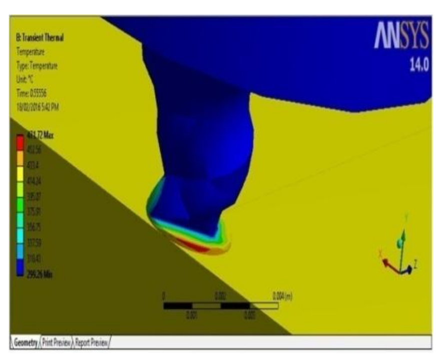
(b) Drill tool profile

Figure 3 ANSYS analysis for deformation for different tool geometry: (a) Cylinder and (b) Drill tool profile

It is evident from the Figure 4(a) of ANSYS 14 for cylinder profile that the maximum temperature exists on nugget zone. Even the heat flux also spreaded on the base plate’s remaining zones on the first impact of kissing bond. The mesh element size for all the tool geometries is taken as $3x10^{-3}$ m. The contact surface are assigned with fine meshing. It is clear that the tool pin profile of cylinder geomtry follows a maximum heat flux dissipation on shoulder, then pin-side and pin-tip surfaces. However the drill pin reacts indifferently. The drill pin having maximum temperature distribution at kissing bond itself.



(a) Cylindrical pin profile



(b) Drill tool profile

Figure 4 ANSYS analysis for transient state heat flux for different tool geometry: (a) Cylinder and (b) drill tool profile

According to the ANSYS analysis,the cylinder tool geometry make the heat generation maximum not only on shoulder it also have the heat distribution shared by pin side surface as well as pin tip. As per deformation, the deformation values are maximum during first impact of kissing bond.

Conclusion

The numerical equations developed predicts the heat generation ratio will be more on tool shoulder. Also the drill pin gets less heat distribution on shoulder and more on the probe side according to deformation theory. However the ANSYS results shows the temperature distribution gets maximum values on shoulder surface for the both tool profiles. But the drill pin have the maximum heat flux on probe tip. The deformation analysis concludes that the drill pin will effects more heat flux due to higher values of deformation on initial kissing bond itself. The drill pin can be concluded as the better choice for the Friction Stir Welding as per this analysis.

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