2005년도 추계 학술발표대회 발표논문, 2005년 11월, 경남 산청

2D ANALYTICAL MODEL OF THE FSW WELD ZONE AND FINITE ELEMENT HEAT TRANSFER ANALYSIS

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ABSTRACT The body of the work covers FSW welding of Al6061 and its thermal distribution based on an analytical model for the heat input at the probe/matrix boundary of Al plates and FSW tool due to the effect of combined translation and rotational motion of the tool pin and shoulder. Finally the 2D- finite element heat transfer analysis program has been used to plot the heat distribution at the Friction Stir Welded joint in Al 6061 plate.

The work concludes that the heat distribution result obtained from FE analysis has a reasonable agreement with the experimentally measured values.

Nomenclature

R_{p1}, R_{p2}	: Radius of pin at top and bottom
R_s	: Radius of shoulder
v_f	: Forward travel speed
v_t	: Pin tangential velocity = 2 R_p ω
v_s	: Velocity of material flowing in shoulder zone
ω	: Rotation speed
h	: Pin length
h_s	: Depth of shoulder processing zone
λ	: Threads per inch
δ^2	: Projected thread area
W_a	: Width of advancing extrusion zone
W_r	: Width of retreating extrusion zone
W_s	: Average width of shoulder zone
ΔZ	: Distance material moves down per revolution

1. Introduction

The friction stir welding is an asymmetric thermo-mechanical welding process in which joining of the base metal occur well below its melting point which result in less distortion and welding stimulate residual stress. As the FSW develops, more scientific research work investigations in this field have also been increased. These research works are carried out in experimental aspects, numerical simulation and development of various analytical solutions to describe the FSW process in greater details. To gain physical insight of the friction stir process in its asymmetric point of view a more detailed analytical models are required.

According to Askari[1] the heat generation due to plastic work is the dominating term during the steady state FSW process. In his model the friction force during steady state FSW process has been neglected as the material in this zone is plasticized and it under go plastic deformation rather than slip at the tool boundary. In the FSW model of A William [2] the metal flow zones are categorized as shoulder zone, extrusion zone and vortex swirl zone. and these zones are defined using regular geometries.

In this present study shoulder zone and the vortex swirl zone are defined same as William's model. But the extrusion zone has been defined using more accurate geometry and a combined analytical and finite element based model has been used for thermal distribution analysis in FSW.

2. Analytical model of heat input

The material flow pattern in FSW from the radiographic visualization has been obtained a shown in schematic of fig1. The extrusion zone is classified as Advancing extrusion zone and retreating extrusion zone. These zones are again classified as Advancing upper and lower extrusion zone and

Retreating upper and lower.

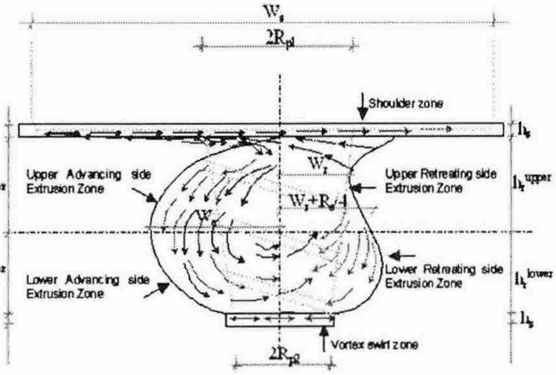

Fig 1. Schematics of metal flow pattern of FSW

The advancing lower extrusion zone and Retreating upper and lower has been defined using parabolic geometry and the advancing upper extrusion zone is defined using a geometry as shown in fig 1.

Volume per unit time of the die cavity formation from fig 2

$$V_{DC} = V_f (R_{p1} + R_{p2}) ht$$

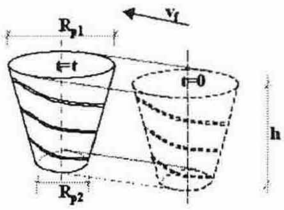

Fig 2. The die cavity formation details of FSW pin

Volume of the material moving through the extrusion zone

$$V^e = V^a + V^r$$

Where V^a - volume of the material moving through the advancing side of extrusion zone

V^r - Volume of the material moving through the Retreating side of extrusion zone

Volume of the material moving through the advancing side of extrusion zone

$$V^r = V^a{}_{upper} + V^a{}_{lower} - die \quad cavity$$

$$V^r_{upper} = \left(V_f + V_t\right)\left[W_r^2 h_r^u + \frac{W_r R_s}{2} + \frac{R_s^2}{8} + \lambda \delta^2 h_r^u\right] t$$

$$V^r_{lower} = \left(V_f + V_t\right)\left[\frac{4}{3}\left(W_r + \frac{R_s}{4}\right) + \lambda \delta^2\right] h_r^l t$$

Volume of the material moving through the Retreating side of extrusion zone

$$V^a = \left(V_f - V_t\right)\left[\frac{4}{3} W_a + \lambda \delta^2\right] ht$$

Total volume of extrusion zone

$$V^e = V^a + V^r$$

Assuming the material moved down one tread pitch (1/λ) per revolution, total downward motion

$$\Delta Z = \omega t / \lambda$$

Also assuming that the shoulder material fills the volume vacated y the downward motion

$$h_s = \Delta Z$$

Width of the shoulder processed zone

$$W_s = R_s - R_p$$

Velocity of the material flowing through the shoulder zone

$$v_s = \omega \pi \left(R_s + R_p\right)$$

Total volume per unit time of the shoulder processed material

$$V_s = t^2 \omega^2 \left(R_s{}^2 - R_p{}^2\right) \pi / \lambda$$

The plasticized metal is not allowed to expand freely due to the containment of its solid surrounding and the axial force from the tool. This result in the expulsion of metal at the top surface and the rotation of the tool transport these expulsed metal and deposited them in the retreating side. In this work this volume is assumed as 2~4% Vs depending on the rotation speed Equating the flow for mass balance

$$V_{DC} = V^e + 0.98 V_s$$

Solving this equation width of retreating and advancing side are calculated.

And finite element heat transfer analysis has been carried out.

3. Non-linear Heat- transfer analysis

The thermal analysis was conducted using temperature dependent thermal material properties as shown in fig.3. From conservation of energy the governing equation of heat conduction in weldment is obtained (considering the medium to be isotropic). Applying the error distribution principal known as Galerkin method, and setting the n-integral form to zero and then applying Green-Gauss theorem the elemental formulation can be finally written as [5]

$$[k]\{\phi\} + [c]\left\{\frac{\partial \phi}{\partial t}\right\} = \{f\}$$

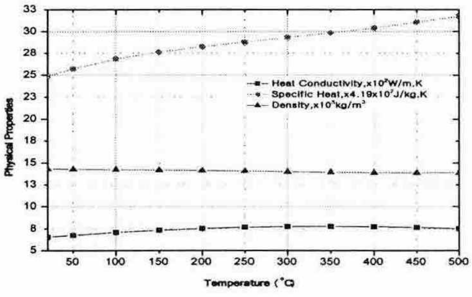

Fig 3. Temperature dependent Physical properties of Al6061

Where

$[k]$ - Conductance matrix

$[c]$ - Heat capacity matrix

$\{f\}$:- Load vector

Using this formulation the finite element code is developed for the heat transfer analysis.

4. Temperature measurement: Experimental and Numerical

Friction Stir welding was carried out on joining two Al 6061 plates (LxWxH=100mm x70mm x12mm) with thermocouple placed in the following positions as shown in the fig.4

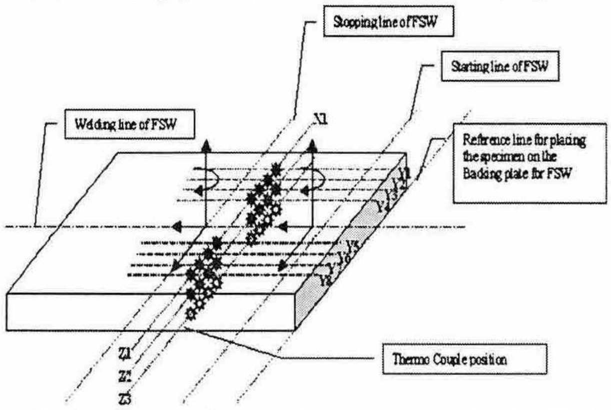

Fig 4. Schematic of temperature measurement during FSW of Al6061

The developed specialized finite element code has been used to analyze the heat conduction process in FSW. A mesh model generated has Nodes=3575 and elements=3408.The heat input area has been decided based on the analytical model and the tool area is not considered in this heat transfer analysis. So the tool area has been taken as non-existing elements.

5. Result and discussions

The temperature contour obtained from the Thermocouple Experiment is as shown in fig.5.

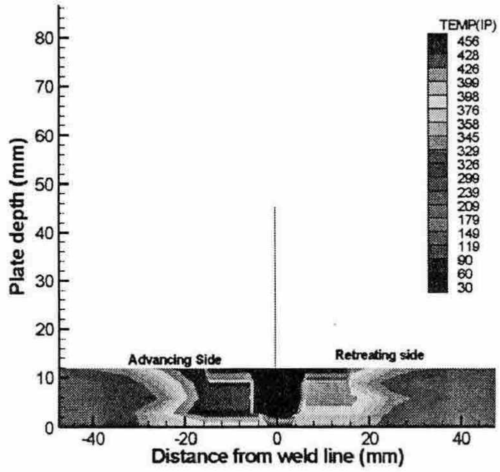

Fig 5. Temperature Contour for FSW of 50-travel speed and 600-rotation speed measured using thermocouple

The temperature contour obtained form the numerical analysis is as shown in the fig 6. Calculated results have a good agreement with experimental results.

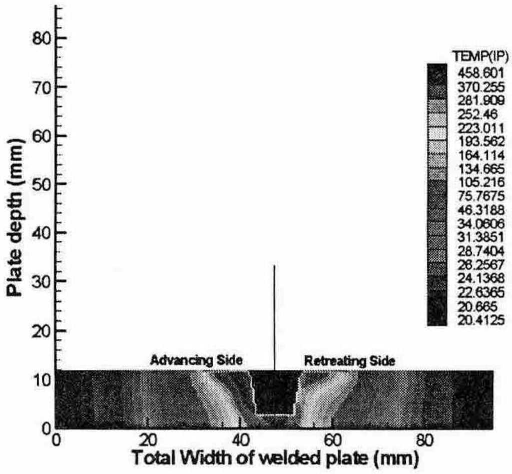

Fig 6. Temperature Contour for FSW of 50-travel speed and 600-rotation speed obtained using the analytical model and non-linear heat transfer analysis.

References

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