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Research Paper Engineering

Thermal Modeling and Analysis of Friction Stir Welding

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ABSTRACT

Friction Stir Welding (FSW) is a revolutionary solid state welding technique. The amount of heat generated at the interface of tool & workpiece determines the quality of the welding. The heat flux must keep the maximum temperature in the workpiece high enough so that the material is sufficiently soft for the pin to stir but low enough so the material does not melt. Therefore thermal analysis of this process has very much importance. In this paper an attempt is made to simulate the FSW process in order to understand the temperature distribution during the FSW process using ANSYS. The main aim of this research work is to develop a simulation of Friction Stir welding & validation of the same with the available experimental data. ***SUMMARY*** *In this paper computational simulation of Friction stir welding was carried out using Ansys software. Heat flux equation was used for the application of heat flow to the workpiece. The simulated results are inline with experimental results.*

Keywords : Thermal modelling, Tool, Pin, shoulder, Heat flow

INTRODUCTION

Friction stir welding (FSW) was invented in 1991 by The Welding Institute, a research and technology center based in the United Kingdom [1]. FSW is a solid-state welding technique with a wide spread applications in many areas including Automobile, Shipbuilding & Aerospace industries.In this process the material that is being welded does not melt and recast.

FSW is carried out with a rotating tool with the combination of heat & stirring motion which softens & mix the material on the weld line of the two sheets to be welded. FSW tool is made of material which has superior higher temperature properties than the material of the work piece. The Key components of FSW tool are: a shoulder and a pin.

- The shoulder: This is the primary means of generating heat during the process, prevents material expulsion and assists material movement around the tool.
- The pin: The pin's primary function is to deform the material and its secondary function is to generate heat [2].

2. THE PROCESS OF FSW

In FSW a non consumable rotating tool with a shoulder & pin is inserted into the joint line between the two plates or Sheet. The length of the tip of tool is slightly less than the weld depth required.

Before the pin penetrates the plates the two plates to be joined are oriented and clamped rigidly with appropriate fixtures in such manner that the rotating tips of the tool do not forced apart two plates. The tool continues to plunge into the weld line on the two plates to be joined until the shoulder of the tool comes into the contact with top surface of the two sheets. After that the forward motion of the tool is initiated.

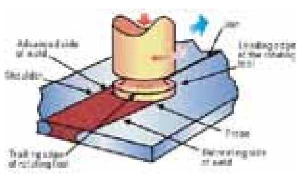

Fig. 1 A schematic of FSW Process

As the tool moves forward on the weld line with constant speed, heat is generated due to the friction between the tool & work piece. Generated heat softens the work piece material & the combined action of the rotating shoulder and pin produces a mixing of the material. Thus continuous welding is carried out with the forward motion of the tool.

The most important factor in FSW process is the heat generated between tool & work piece. The temperature must be high enough so that it can initiate material flow around the tool pin, but not high enough upto an extend that it may melt the work piece material. The maximum temperature generated by FSW process ranges from 70% to 90% of the melting temperature of the work piece material to minimise the defects generally found in conventional fusion welding techniques [3].

If the temperature is insufficient to initiate material flow in workpiece, there would be excessive load on the tool pin and it may break the tool pin. Therefore thermal analysis of this process is very important.

FEA can be used for thermal analyses to evaluate the temperature distribution during the FSW process.

3. EXPERIMENTAL DETAILS

X.K. Zhu & Y.J. Chao [4] conducted FSW to join two thin plates of 304L stainless steel. Welding was performed on the friction stir welding process development system, FSW-PDS.

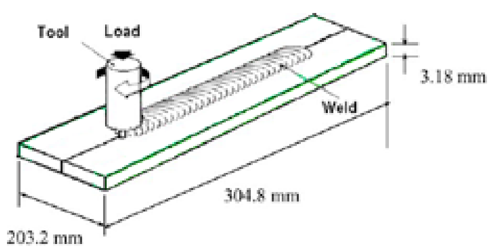

Fig. 2 Geometry configuration of friction stir welding conducted by X.K. Zhu & Y.J. Chao

Each plate used for welding has length 304.8 mm, width 101.6 mm & thickness 3.18mm. The tool was made of tungsten alloy. The tool has shoulder radios of 9.525 mm & pin radios of 3.175. The welding of 304L plates was carried out in single pass with tool rotational speed of 300 rpm & downward force 31.138 KN. The total welding time was 165s. The temperature history was recorded during FSW using thermocouples[4].

4. SIMULATION OF FSW PROCESS

Finite Element program ANSYS is used for the simulation of FSW process in which Thermal model is developed using Ansys. The purpose of thermal model is to calculate the transient temperature fields developed in the workpiece during Friction stir welding.

4.1 APPROACH OF SIMULATION

Friction stir welding simulation is carried out using transient thermal module of ANSYS. Heat is produced in the friction stir welding process due to the friction between the tool shoulder and workpiece interface which is the driving force for the successful welding.

Thus for the application of heat flow, cylindrical coordinate system is implemented on the workpiece, and heat flow is applied at each node as moving heat source at each instantaneous time step to evaluate the temperature distribution on the workpiece.

4.2 APPLICATION OF HEAT FLOW

The total heat input □ in watts for this model is calculated through Chao et al. equation. The total heat input □ is given by equation

$$Q = \frac{\pi \omega \mu F (r_s^2 + r_s r_t + r_t^2)}{45(r_s + r_t)}$$

Where ω is the tool rotational speed, μ is the frictional coefficient, F is the downward force, and rs & rt are the radios of Tool shoulder & Tool Tip respectively.

Fig.3 shows the application of heat flow on the workpiece.

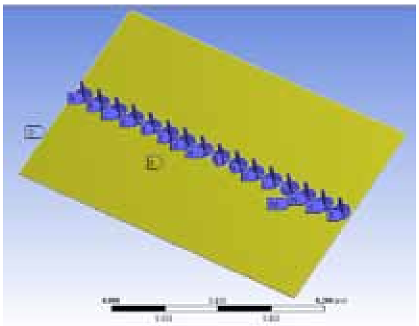

Fig. 3 Application of heat flow to the workpiece

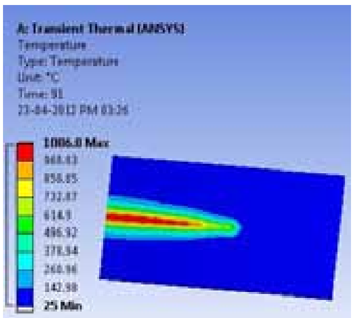

Fig.4 Temperature distribution on top surface of the workpiece at welding time 91 second

5. VALIDATION OF THERMAL MODEL OF FSW

For validating the thermal model developed using ANSYS, it was essential to correlate the developed model with the published results. For this purpose, the developed thermal model was verified with experimental results obtained by Zhu and Chao[4].

Zhu and Chao's experimental details are mentioned in previous section.

Measurement of temperature was made by Zhu and Chao using thermocouples on top and bottom surface of the workpiece perpendicular to the weld line.

The Graph in fig 5 shows the comparison of simulated and experimental results for top surface of the workpiece at welding time t=83 sec.

The Graph in fig 6 shows the comparison of simulated and experimental results for bottom surface of the workpiece at welding time t=83.

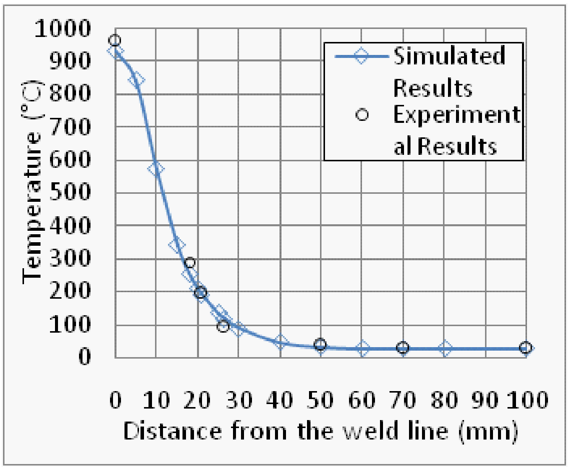

Fig.5 Comparison of temperature distribution on top surface of w/p along the transverse direction at welding time t= 83 s

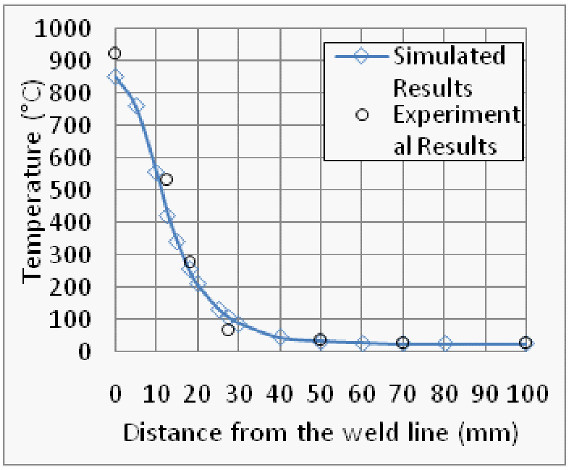

Fig.6 Comparison of temperature distribution on bottom surface of w/p along the transverse direction at welding time t= 83 s

6. CONCLUSION

A three dimensional thermal model is developed for the simulation of Friction stir welding using transient thermal module of ANSYS.

- It is clear from the results that moving heat source technique is reliable for the simulation of FSW process.
- It is seen that the highest temperature during the welding is distributed within the shoulder region.
- It is found that the temperature decreases in a direction perpendicular to the weld line
- The simulated model is validated with the published experimental results which shows that the simulated results are inline with experimental results

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