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Evaluation of Temperature Distribution of Solid State Welded AA6061Alloy

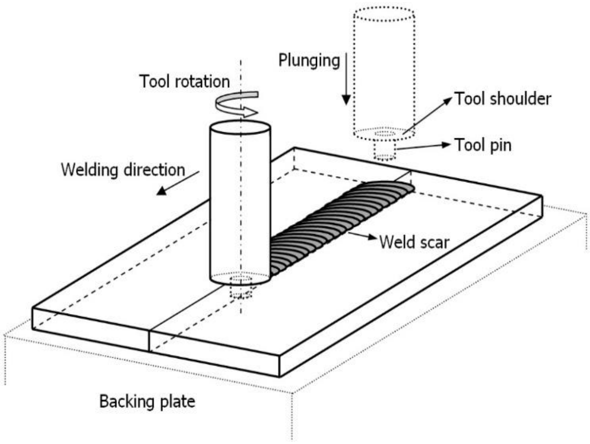
Santhosh V[#1], Natarajan U[*2]
[#]Alagappa Chettiar Govt. College of Engineering and Technology
Karaikudi, TamilNadu, India

Abstract
The amount of heat generated between the shoulder and the Workpiece during solid-state weld dictates the quality of the processed zone. Since direct temperature measurements of the welded region are not possible, a numerical model was developed to predict the temperature in this area. Hence understanding the distribution of heat and obtaining the temperature contours will assist in understanding the general process of solid-state welding. A three-dimensional finite element model is developed to study the temperature history in the butt welding of AA6061 aluminum alloy using COMSOL software. The variation of temperature with respect to thermal conductivity, specific heat, and density was developed. The predicted peak temperature is used to obtain the temperature contours throughout the Workpiece. The results suggest that the temperature achieved during processing plays an important role in determining the properties of the processed Aluminium alloy.

Keywords - *Solid state weld, Temperature History, COMSOL software.*

I. INTRODUCTION

This first commercial application of this welding technique is believed to be the joining of AA6061 extrusions used for fishing vessels. Due to the low distortion, FSW is optimal for welding flat panels and opens opportunities to be also used for welding bulkheads and decks components. Friction Stir Welding (FSW) is an efficient, environment-friendly solid-state welding without melting in the workpieces, joining technique that is intended to be used for joining of especially the Aluminium alloys, besides dissimilar welds, which are difficult to weld with traditional welding techniques. Joining of large panels, which cannot be easily heat-treated post-weld to recover temper characteristics, is another common interest for FSW to be preferred for industrial applications besides its other benefits. It was invented and experimentally proven by Wayne Thomas and his colleagues at The Welding Institute, Cambridge, the UK in December 1991, and then TWI for world-wide patent protection in December of that year. In FSW, a cylindrical-shouldered tool, with a cylindrical/profiled, threaded or unthreaded probe (pin), is rotated at a constant speed and moved at a regular traverse rate in the joint line between two pieces of material, which are butt welded together as shown in Figure 1. The parts have to be clamped rigidly onto a backing plate in order to prevent the abutting joint faces from being forced apart but also to support the high plunging forces applied by the FSW machine head. The length of the pin is slightly less than the required weld depth, and the tool shoulder should be in direct contact with the surface of the workpieces. The probe is submerged into the workpieces, and then the tool is moved along the weld line with a tilt angle of 2-4 degrees, increasing the pressure under the tool shoulder.



II. EXPERIMENTAL PROCEDURE

Experimentswerecarriedout underdifferentweldingparametersin ordertousethe measuredtemperaturedataforverificationoftheaccuracyof thethermalmodel.The temperature measurementduring welding isdiscussedin thissection.

The two workpieces to be welded, with square mating (faying) edges are clamped on a rigid backing plate. The clamping prevents any movement of workpieces during welding. The shank, shoulder, and pin form a welding tool, and this tool can be rotated to a prescribed speed and maybe tilted normal concerning the Workpiece. The device is slowly plunged into the workpiece material at the butt line until the shoulder of the tool forcibly contacts the upper surface of the material, and the pin is at a short distance from the backplate. Either the rotating mechanism is made to move, along the bust line, to the end by applying an axial force or the Workpiece is moved to the same effect.

The parent metal was prepared into sizes of 150 × 75 × 5 mm for welding shown in figure 1 the pin is withdrawn on reaching the end which leaves a keyhole. The pin is forced or plunged into the Workpiece until the shoulder contacts the surface of the Workpiece. As the tool descends further, its shoulder surface touches the top surface of the Workpiece and creates heat.

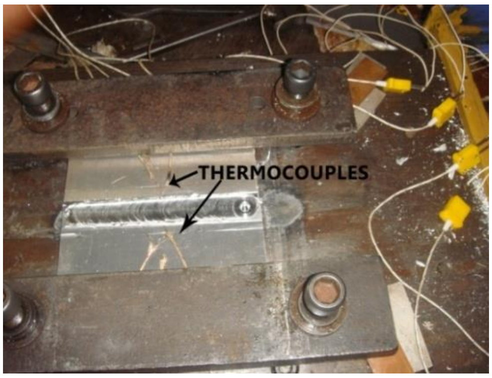


Figure 1: FSW machine

A. *Temperature Measurement*

To measure the temperature during welding, the K Type thermocouple was used. The range of the thermocouple was 95°C to 1260 °C. Another requirement was on the smaller diameter of the hot end of the thermocouple since sensitivity was of prime concern. The hot end diameter of the thermocouple was 1.5 mm, the cold end was fixed to a thermocouple bank, and this was, in turn, connected to the data acquisition system. Thermocouplesareattachedto a DAQ system that could measure the data at 15 Hz. The temperature is measured every second and stored in the computer. The time data corresponding to the collected temperature data is also stored in the computer to find the thermal history of the weld specimen during the welding process. Temperaturedatacollectionis has done through a DAQ systemthatisattachedtothelaptopcomputerrunningLAB VIEWsoftware.

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III. NUMERICAL MODELLING

Applying FEM modeling to predict thermal history and residual stress has become a fairly common practice at present. In this analysis, COMSOL software was used to predict the temperature distribution and residual stress of FSW AA 6061 aluminum alloy joints. COMSOL software contains smaller packages called modules. The modules can be easily combined to couple the governing equations of the respective physics used for the modeling of heat transfer in welds; an advantage will be the ability to couple physics from solid mechanics and heat transfer relationships.

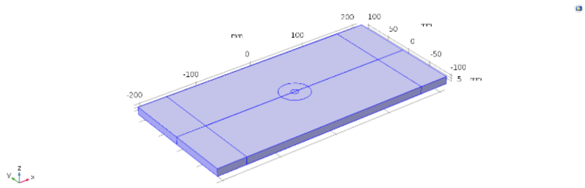

Figure 2: Schematic representation of Workpiece

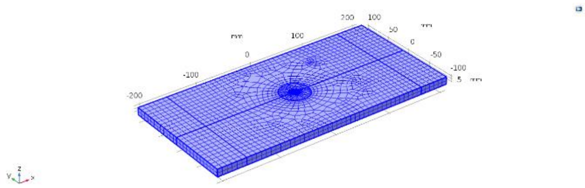

Figure 3: Meshed Workpiece as well as a tool utilized during simulation of friction stir welding

IV. RESULTS AND DISCUSSION

The nonlinear thermal simulation of the welding process is modeled and analyzed. The thermal gradient of higher temperature to lower temperature and their distribution from the weld center in the transverse direction was clearly observed by the difference in color contour. Due to high thermal conductivity, the heat generated at the weld center due to welding is readily transferred to the next region. Because of this, the differences in temperature with respect to distance changes at every instance as the weld ramp proceeds. Figure4 shows the predicted temperature distribution numerically for the optimized process parameters. As shown in the figure, the maximum temperature was found at the center of the top surface, reaching 712.2°K that is just below the solidus temperature of AA 6061. The numerically predicted peak temperature is within the generally accepted temperature range in the stir zone of the weld. The maximum temperature was 712.2°K, 82.71% of the melting heat of the material (861°K), which was observed at the stir zone due to the rotating pin and forging action of the shoulder.

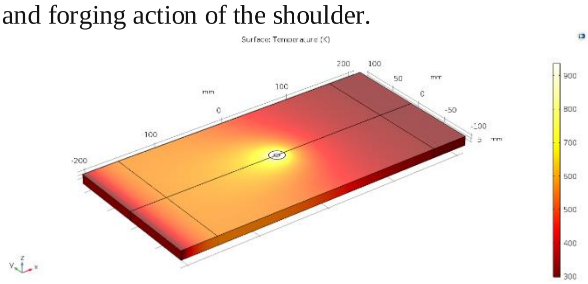

Figure 4: Predicted temperature field (in ° K)

Peak temperature in the Workpiece is obtained close to the edge of the tool shoulder, and significant spatial gradients of temperature exist in the vicinity of the tool surfaces. Measurements of temperature close to a rotating tool are difficult. The material transport caused by the motion of the tool makes it difficult to focus on a single location; the pin portion of the tool is subjected to the next higher temperature of 700ºK. Even though the width of the plate is only half in the length of the weld specimen, the distribution of the temperature generated during the welding process is asymmetric due to stirring effect of the pin and spread over across the weld direction in the range of 700 - 340.54ºK

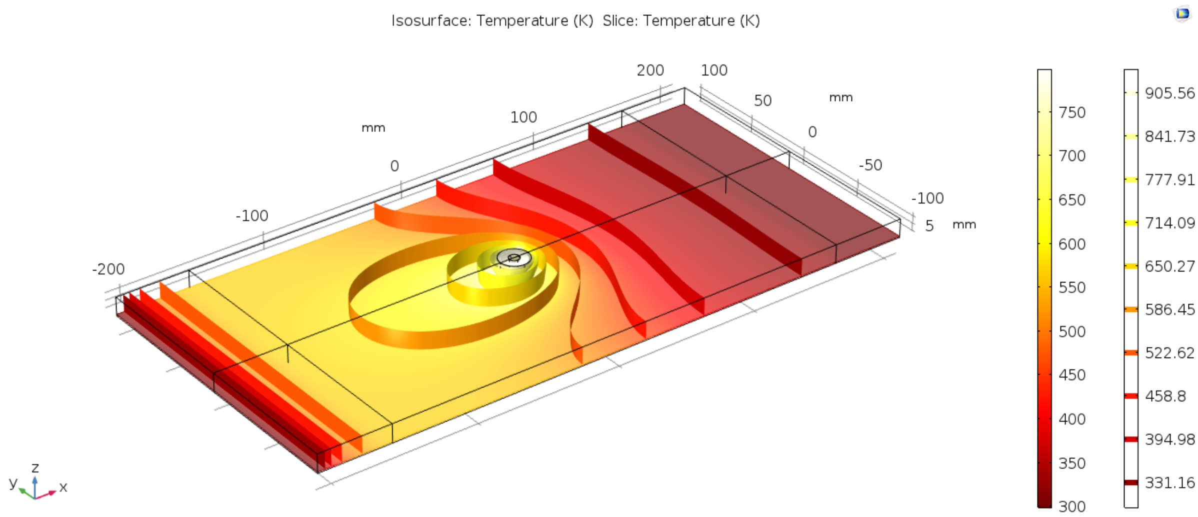

Figure 5: Weld pool temperature distribution in the form of the iso-surface plot

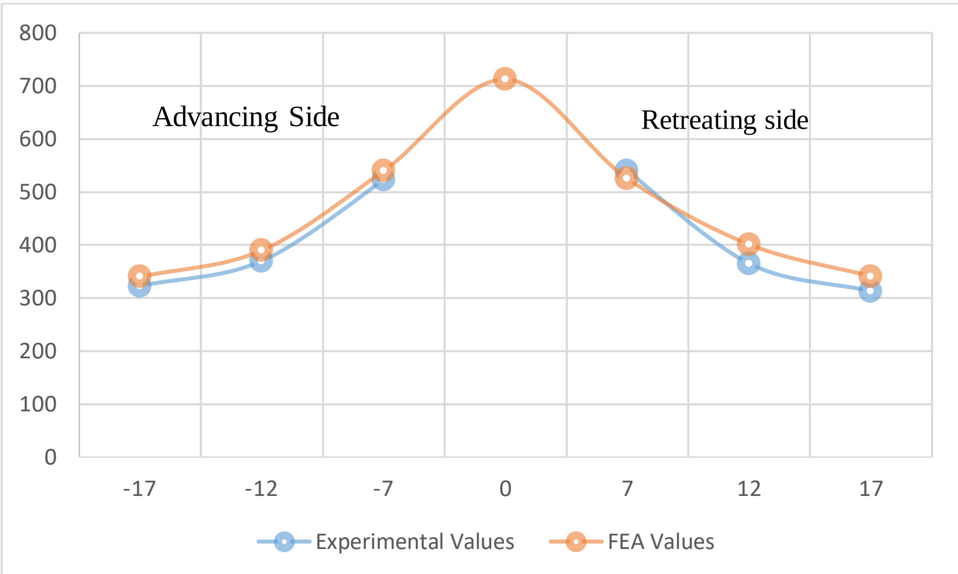

Figure 6: Comparision between Experimental and Numerical Result

Figure 5 shows the weld pool temperature distribution in the form of iso-surface plots. The temperature is highest, where the AA 6061 is in contact with the rotating tool. Behind the tool, the process transports hot material away, while in front of the tool, new cold material enters. This could be visually observed from the above plot, and the temperature at the pin location has a uniform temperature of 691.59°K due to the transport of hot material. The advancing side of the weld regions is heated up and maintained at a temperature of 510°K even at the end of specimen.

Figure 6 compares the predicted and measured temperature history for weld, which was obtained with optimized process parameters. The important observation made from this plot is that the experimental and numerical temperature distributions match reasonably well.

V. CONCLUSIONS

FSW process parameters (rotational speed, welding speed, and axial force) optimization, characterization of mechanical properties, temperature distribution and were studied. The predicted values of temperature using the nonlinear three-dimensional FEA model are in good agreement with the experimental values. The peak temperature of 712.2°K was predicted at the stir zone due to the rotating pin's stirring action and forging action of the shoulder. When the distance increases from the centre of the weld, temperature decreases gradually. The temperature on the advancing side was slightly higher than on the retreating side in FSW process because the material experiences the highest strain rate, and strain is on the advancing side of the weld.

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