B. Finite Element Modeling Of Heat Transfer In Friction Stir Welding With Proper Boundary Conditions

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Introduction

A 3D transient heat transfer model for friction stir welding (FSW) of the AL6061-T6 with CPM 1V tool steel incorporating moving the tool over the workpiece involving the thermal effect during the initial penetration of the tool pin with adaptive boundary conditions and temperature varying material properties is presented in this paper. Final temperature profile is influenced to a large extent by the heating and cooling rates of workpiece which depend on the boundary conditions. Predicting a realistic peak temperature becomes important as the operating temperature at the interface of tool-workpiece is very close to the solidus temperature of the aluminum workpiece. The thermal history of the workpiece from finite element simulation is validated with the experimental results, and the conformity is presented.

Procedure

The convection heat-transfer coefficients of the surfaces exposed to the air can be theoretically determined using Newton's law of cooling. The contact conductance between the workpiece and backing plate depends on the pressure at the interface and has a non-uniform variation laterally and longitudinally. The actual pressure distribution along the interface is dependent on the thermal stress developed in the process due to heating and cooling of the workpieces and on the mechanical pressure applied by the tool on workpiece. In order to make the thermal model more robust, the non-uniform contact conductance profile is determined based on the stress at the interface of workpiece and backing plate. The control equations in the thermal and structural models were solved with a commercial finite element (FE) code.

Results and Discussion

Two 6061-T6 Al alloy plates, each with a dimension of 200 X 50 X 6.4 mm are butt welded in an adapted vertical milling machine for FSW. The tool made of CPM 1V tool steel, consists of a shank, shoulder, and pin with radii of 9.5, 12, and 2.6 mm, respectively. The temperature dependent material properties of aluminum alloy 6061-T6 and CPM 1V tool steel are considered during the model development. The plates are prepared to measure the temperature at four points using thermocouples. On each plate, four 1.5-mm diameter holes were drilled on one side of the plate. Type-K thermocouples of 1-mm diameter are subsequently inserted into the holes and glued so that the thermocouple ends are in intimate contact with the workpiece.

A finite element thermo-mechanical model for AL6061 with a mechanical tool loading is developed that considers a uniform value for the contact conductance and that value is used for predicting the stress [Fig. 1] at the workpiece and backplate interface. These pressure distribution contours define the non-uniform adaptive contact conductance profile and values used in the thermal model for predicting the thermal history [Fig. 2] of the workpiece. The computed temperatures from FE model at the positions of the thermocouples are found to be in very close conformance with the results obtained experimentally [Fig. 3].

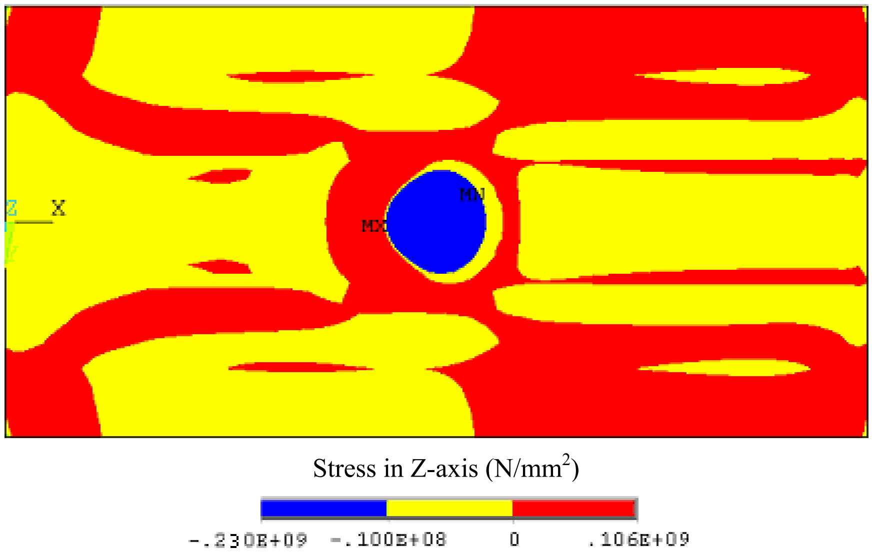

Figure 1. Stress distribution at the bottom of workpiece when tool is at the center of the workpiece

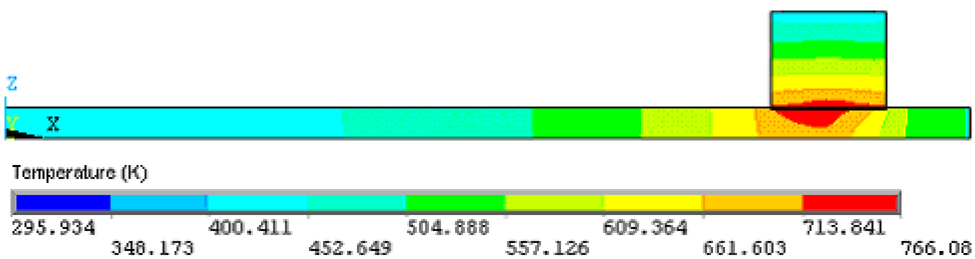

Figure 2. Calculated temperature field distribution for the integrated tool-workpiece model in the longitudinal section along the joint line (V = 133 mm/min, ω = 344 rpm)

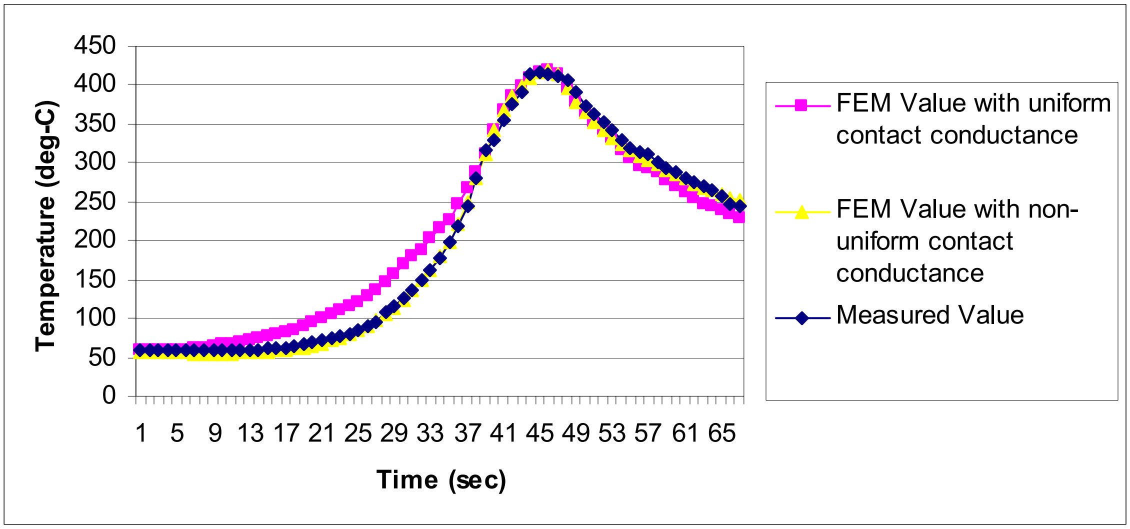

Figure 3. Comparison of the modeled and the measured temperature history for workpiece Temperature-time profile for thermocouple location 6mm from the joint line (V = 133 mm/min, ω = 344 rpm)

Conclusions

In this paper, a thermo-mechanical model to predict the thermal history with an adaptive contact conductance at the interface of the workpiece and backing plate is developed. The stress/pressure at the interface of workpiece and backing is used to define the contours of the non-linear contact conductance. The contours are adaptively modified after each load step as the tool moved over the workpiece. A comparison of the temperature profile developed using the adaptive and uniform contact conductance with the experimental results showed the possibility of a more accurate determination of temperature profile of the workpieces.