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PREDICTION OF TEMPERATURES DURING FRICTION STIR WELDING OF AA6061 ALUMINIUM ALLOY USING HYPERWORKS

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ABSTRACT

This document contains the formatting information for the papers presented at the International conference on "Engineering Technology International Conference". The conference held at (Bali, Indonesia) during August 10-11, 2015. The microstructure and mechanical properties of the material to be welded mainly depends on the temperature during welding. The difficulty in measuring these temperatures during friction stir welding, pose a serious concern to researchers, practicing engineers and technicians. Hence, there is a necessity for searching alternate solutions. In the present research, a simulation model has been developed by using hyper works software to estimate the temperatures and flow stress. The modeling of Friction Stir Welded AA6061 alloy has been carried out by three dimensional nonlinear FEA model, the temperatures are evaluated. During the welding process the peak temperatures and flow stresses are presented around the rotating tool pin, and plates are found to be 615 ^{0}C and 450 ^{0}C.

Keywords: FSW, AA6061, peak temperature, FEA, hyper works.

INTRODUCTION

Friction Stir Welding (FSW) is a solid state welding process, in which the material being welded does not melt which has been developed in 1991 by The Welding Institute (TWI) [1]. The welding joint is formed due to the frictional heat generated between the work piece and shoulder of the rotating tool, which results in plastic deformation and the material flows from the advancing side to retreating side. Technologists and designers had faced many challenges in the welding of aluminium alloys by conventional fusion welding because of the defects like hot cracking, distortion and porosity. When compared to conventional fusion welding process there are many advantages of FSW, which has been reported by many investigators [2]. During welding it is important to measure the temperatures distributed in the welding zone and heat affected zone, since the mechanical properties are influenced by temperature distribution and heat generation [3]. The measurement of temperature distribution in the stir zone will be difficult due to intense plastic deformation, and can be estimated by microstructure analysis or by incorporating thermocouples adjacent to the rotating pin. The temperature distribution can also be predicted by using numerical analysis. Many investigators across the world have studied extensively the numerical analysis of FSW joints during the last two decades.

Sato *et al.* [4], studied the microstructural evolution of AA6063 aluminium alloy during friction stir welding with transmission electron microscopy (TEM) at various locations from the weld centre. It has been reported that the temperature distributions at the locations 10, 12, and 15 mm away from the weld centre were 353, 302, and 201 ^{o}C respectively. And the temperature at the weld centre was observed to be more than 402 ^{o}C, due to which the precipitates are completely dissolved in aluminium matrix.

Mohoney *et al.* [5], investigated the temperature distribution of friction stir welded AA7072-T651 alloy having thickness of 6.35 mm. The edge of the stir zone measured maximum temperature of 475 ^{0}C, and the temperature in the stir zone decreases from top to bottom surface of the plate.

Frigaard *et al.* [6], discussed friction stir welding of age hardening of aluminium alloys by developing a finite difference thermal model. It has been reported that for welded joints of AA 6082-T6 and AA7108-T79, the measured temperature profile was correlated with predicted temperature profile for a moving heat source. Investigations by Rajesh *et al.* [7], on analysis of complex heat flow phenomena for friction stir welded joints using 3D finite element heat transfer analysis program, the heat distribution was plotted in AA6061 alloy. It has been reported that the analytical and asymmetrical model predicted the heat input, which is the combined effect of tool rotational speed and welding speed. The values obtained from the model are validated by experimental values. Yin *et al.* [8], studied the numerical simulation of temperature distribution for AA1100 aluminium alloy in quasi steady state. He reported that a numerical model was developed by using finite element software COSMOL to estimate heat generation due to the plastic deformation and the temperature field obtained by quasi-state analysis matched with experimental data.

Xu *et al.* [9], investigated the experimental and numerical study of thermal process for friction stir welded aluminium magnesium alloy AA5083-H116 plates. The temperatures are measured by using embedded thermocouples and infrared camera, and these values are correlated with numerical values. In AA 2219 aluminium alloy by using 3D finite element mathematical model and ANSYS software the temperature distribution at various locations were calculated, and the temperature gradient is low at the bottom and high at the top of the plate[10].

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Cox *et al.* [11], studied the modelling the effects of an axial force and control of an elevated tool temperature of AA6061- T6 aluminium alloy by using 3D computational fluid dynamics model(CFD). He reported the simulation of rotating tool and maintained at a higher temperature, which showed that in the region behind the tool there was a lower plastic strain.

Chao *et al.* [12], investigated the heat transfer in friction stir welded AA2195-T8 by experimental and numerical studies. He found that by considering the rotating tool as steady state boundary value problem, only 5% of heat flows in to the tool, whereas the work piece as a transient boundary value problem the heat transferred was 95% of the total heat generated by friction. In traditional fusion welding the heat efficiency was in between 60 to 80%, but where as in FSW the heat efficiency was high and in the range of 95%.

The viscoplasticity model of the friction stir welding process was studied by using computational fluid dynamics, which showed the temperature field is being effected by tool speeds [13]. The FSW process is a thermo-mechanical phenomena where the material temperature at the weld center was increased up to 80% of the melting temperature, also large shear forces and complex motions are involved [14]. The three dimensional thermal modeling of AA6061-T6, friction stir welded joints was studied by transient heat transfer model for both tool and work piece. This model determined the moving tool pin temperature distribution without any difficulty since a moving coordinate was used instead of a moving heat source, and the predicted results are validated with the experimental values [15]. The analysis of residual stresses and transient temperature for friction stir welded joints AA6061-T6 was done by numerical simulation using ABAQUS/Explicit for quasi-state first stage and ABAQUS/Standard for dynamic second stage. The results indicate that under the shoulder region the temperature gradient was high and at the weld center it is not symmetrical. The longitudinal residual stresses are much higher than the experimental values, due to the fact that only thermal effects are considered, whereas the mechanical reaction between work piece and rotating tool are not considered in this study [16]. The temperature distribution s within the friction stir welded AA6061-T6 was studied experimentally by laying out thermocouples. FSW process was found to be efficient between the temperatures 365 and 390 ^{0}C, and the temperatures on the retreating side are slightly lower than the advancing side[17]. The thermal and thermo-mechanical modeling of welded joints AA6061-T6 was studied by developing a three dimensional heat transfer model by assuming constant heat flux at welding tool shoulder, pure coulomb's friction law and constant contact pressure, to predict the heat and shear stress without considering the tool mechanical effect [18]. A model was developed to study the heat flow phenomena by taking in to account both plastic work and frictional heating, to predict the plastic strains that are formed around the weld zone and there is no longitudinal movement of the tool[19]. The thermal modeling of 6XXX series aluminium alloy was studied by a finite element code ABAQUS, to estimate the heat dissipation during the FSW process [20]. The heat transfer analysis during friction stir welded joints AA6061-T6 was studied by finite element package ANSYS[21]. The thermal history was predicted by using analytical heat input model, and the simulated values are validated with experimental results. The simulations of temperature distribution and flow stress of friction stir welded joints of AA7050-T7451 was studied by Hyper Works software [22].

In this paper a three dimensional model based on finite element method was studied to predict the thermal history and stress distribution in the weld zone. By using a commercial finite element package Hyper Works an attempt is made to study the simulations of friction stir welding process for AA6061 alloy, which includes a specially designed module Hyper Weld.

SIMULATION STUDIES

The simulations were carried out using Altair Hyper works software using Hyper Extrude module, Friction Stir Welding. The weld geometry and the type of the weld given as input in software are given in Figure-1. Aluminium plates of size 125 mm× 125 mm× 6 mm are modeled for a square butt joint and shown in Figure-2. The tool profile and the tool material properties were selected from the data base of Hyperworks 12.0. The tool geometry was selected as a cylindrical tool with a conical pin, having a shoulder diameter of 20 mm, Shoulder length of 15 mm, pin diameter of 5 mm and pin length of 6.5 mm. The tool tilt angle was given as 3^0 for the input. The axial force of 1.5 kN was kept constant as the tool tilt angle during the process of weld simulation. A nonlinear thermo-mechanical analysis has been carried out until the solution converged.

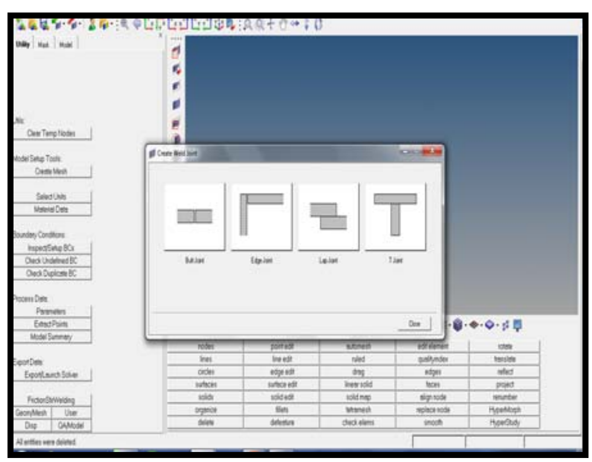

Figure-1. Schematic diagram of square butt joint in hyper extrude.

The results obtained from the simulations are given in preceding section. The mechanical and thermal analysis was done utilizing standard algorithms. The

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element selected for the analysis was default 3 dimensional Hexahedral element with 20 nodes. The element has capacity of 3 degree of freedom and serves both for mechanical and thermal analysis. The three dimensional isometric view of the developed model with lower mesh density is given in Figure-3. The process/input parameters for the simulation given as input and are shown in Figure-4. The tool material properties are shown in Figure-5.

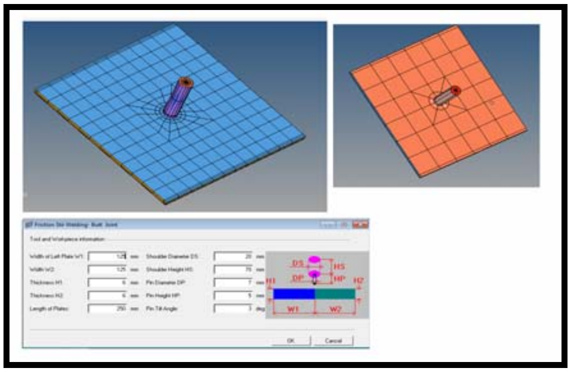

Figure-2. Three dimensional isometric view of meshed plate in hyper extrude.

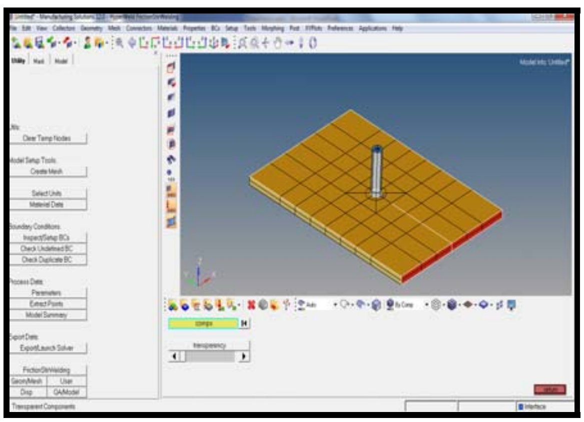

Figure-3. Three dimensional isometric view of meshed plate in hyper extrude.

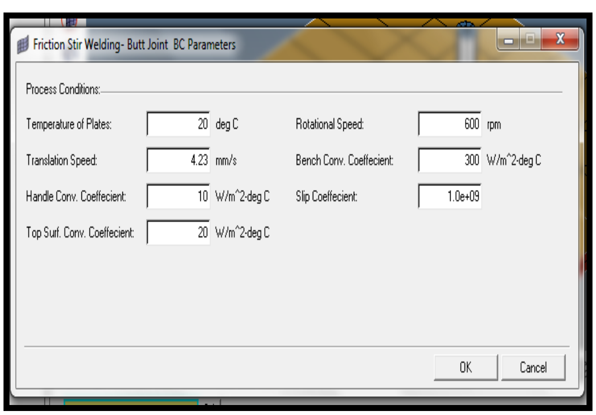

Figure-4. Input parameters in hyper extrude.

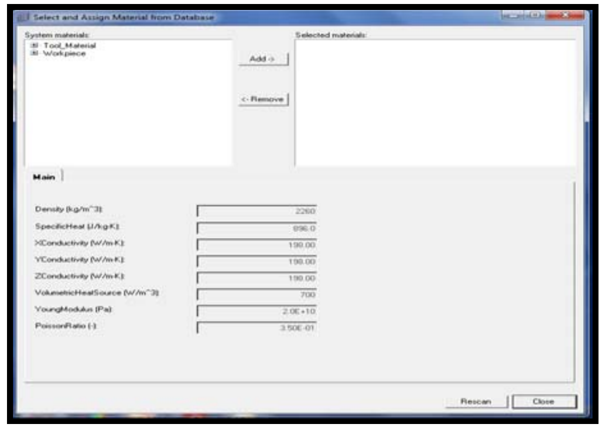

Figure-5. Tool material properties in hyper extrude.

RESULTS & DISCUSSION

The present simulations have been carried out at two level of different input parameters, rotational speed of the tool 1000 rpm and 1600 rpm and traverse speed 40 mm/s and 160 mm/sec. The temperature distribution along the weld joint and the temperature at the tool interface were recorded during the process of the weld. From Figure-6 it is clearly visible that the temperature in the tool is around 890.09 deg C where as at the interface it is around 794.2 deg C. The actual temperature in the plates was around 487.1 deg C which is clearly visible. The Heat Affected Zone is also clearly visible in the figure showing the variance of temperatures. However, in AHW 12.0, the temperatures were not updated to deg F since the input was in deg F and results were in deg C, the same has been reported to Altair for a possible solution. As the traverse speed is increasing keeping the rotational speed constant at 1000 rpm there is a further increase in temperature in the tool up to 1661.02 deg C. However, the temperature in the plates is still around 503.9 deg C to 407.1 deg C. This may be due to the frictional heat increase due to increase in traverse speed. This phenomenon is clearly given in Figure-7. A similar phenomenon is observed when there is an increase in rotational speed and decrease in the traverse speed to 40 mm/s. This can be clearly seen in Figure-8. In Figure-9 there is a decrease in the temperatures in the tool and as well as plates when the rotational speed and the traverse speed are increased to 1600 rpm and 160 mm/s, this may be due to the uniform frictional heat developed during the process. The flow stress during the process of simulation is given in Figure-10 and 11. It is clear from the contours that the material flow is uniform around the tool and the stress is around 380Mpa. The yield stress during the process is reported in Figure-12.

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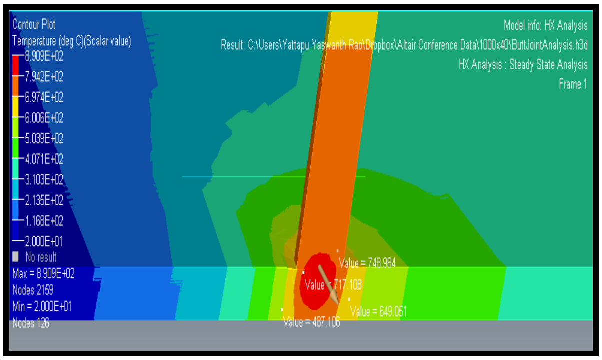

Figure 6. Temperature distribution at 1000 rpm and 40 mm/min.

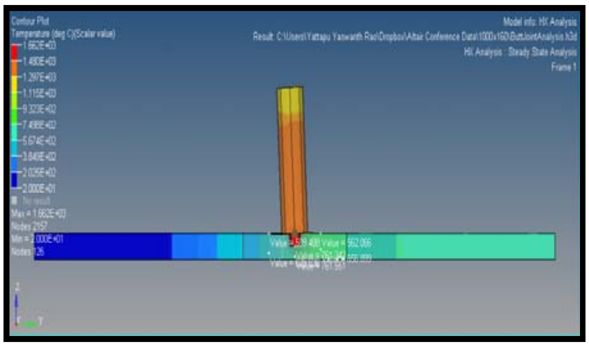
Figure-7. Temperature distribution at 1000 rpm and 160 mm/min.

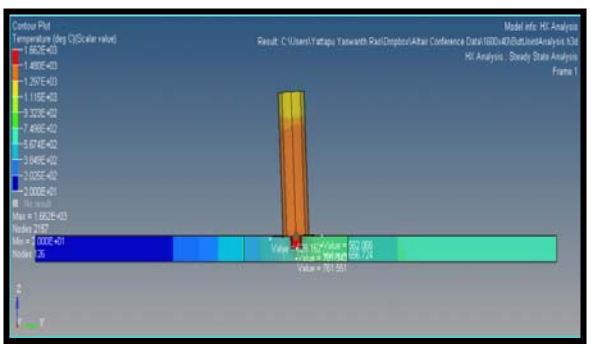
Figure-8. Temperature distribution at 1600 rpm and 40 mm/min.

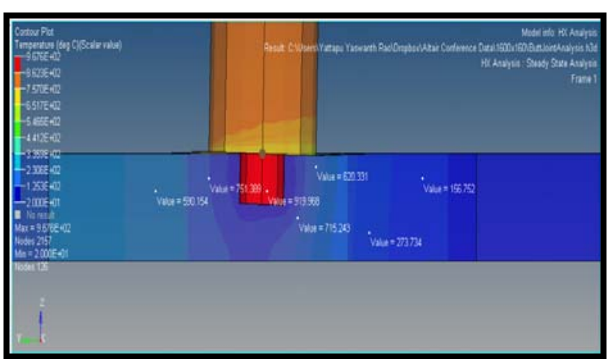
Figure-9. Temperature distribution at 1600 rpm and 160 mm/min.

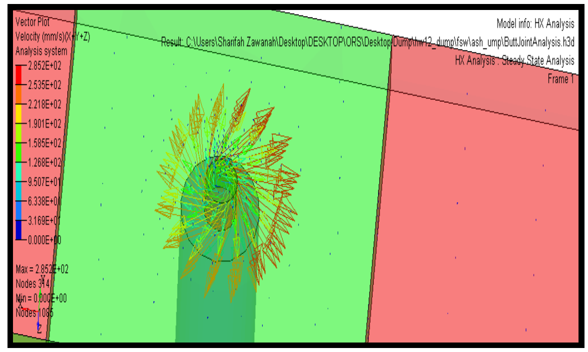

Figure-10. Velocity contours along the tool.

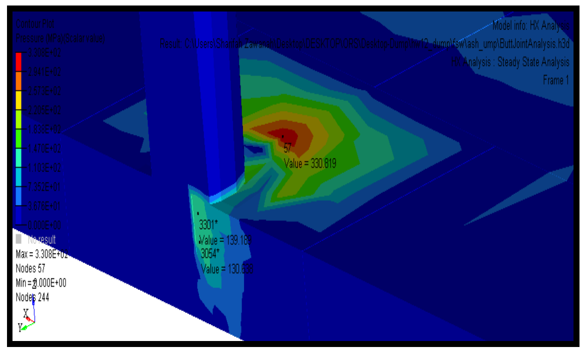

Figure-11. Flow stress during FSW.

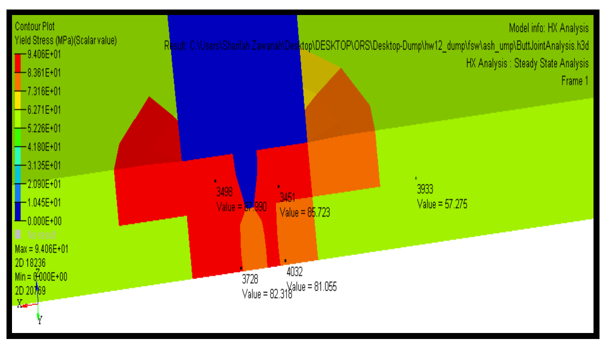

Figure-12. Yield stress during FSW.

CONCLUSIONS

The modeling and simulation of FSW process has been carried out by using Altair's Hyperworks software which can be effectively used to predict the temperature distribution and flow stress for different process parameters at different zones. The results predicted temperature distribution at different zones during the weld vis tool pin, tool shoulder, interface and plates. It has been observed that the temperature is dependent on the frictional heat developed due to increase in rotational speed and traverse speed. The changes in process parameters also play a major role in deciding the quality of the welded sample. Simulation results explain about both yield stress and velocity contours in the weld regions. The temperatures that are seen in the results are very high due to the change in the units of the software from deg C to deg F. However, in all the simulations the welding took place within the melting point of aluminium. The change in units of the temperature in Altair Hyperworks 12.0 is due to the latest version of the software release and has been reported to the concerned who are working on to fix the bug. It can be concluded from the present research that Altair Hyper works can be successfully employed to perform simulation trails prior to experimentation and the same can be justified by simple experimentation.

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