ISSN 2348 – 7968

Replacement of Tool-pin Profile and Simulation of Peak Temperature & Flow Stress during FSW of AA6061 Alloy

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Abstract

Amongst the emerging new welding technologies, friction stir welding (FSW), invented and established by The Welding Institute (TWI) in 1991, is used frequently for welding of high strength aluminium alloys such as AA6061, AA6082, AA6351, etc. which are difficult to weld by conventional fusion welding techniques. This paper presents the modelling of FSW tools by replacement of tool-pin profile along with simulation of peak temperature induced in plate material and flow stresses generated in the same for friction stir welding of AA6061. The modelling has been carried out by using the FEA software. The simulations have been carried out for FSW tools with four different tool-pin profiles modelled and results are presented for variations in peak temperatures of aluminium alloy plate as well as flow stresses generated at and around the tool pin during the welding process.

Keywords: ***Modelling of FSW Tools, Replacement of Tool-pin profile, Peak Temperature, Flow Stress, AA6061, Simulation***

1. Introduction

Friction stir welding being a newly developed welding technology in 1991 at TWI of UK [1] utilizes a non consumable tool with a shoulder & a pin projecting from it. As shown in figure – 1 [2] the pin is plunged into the abutting edges of two plates while rotating and then traversed along the same while the shoulder making firm contact with the surfaces of these two plates.

The frictional heat generated due to rubbing of shoulder & work piece material results in plastic deformation and movement of material from advancing side to retreating side followed by formation of joint behind the tool. The friction stir welding results in substantial change in typical mechanical properties such as strength, ductility, fatigue and fracture toughness of the joint formed [3-9].

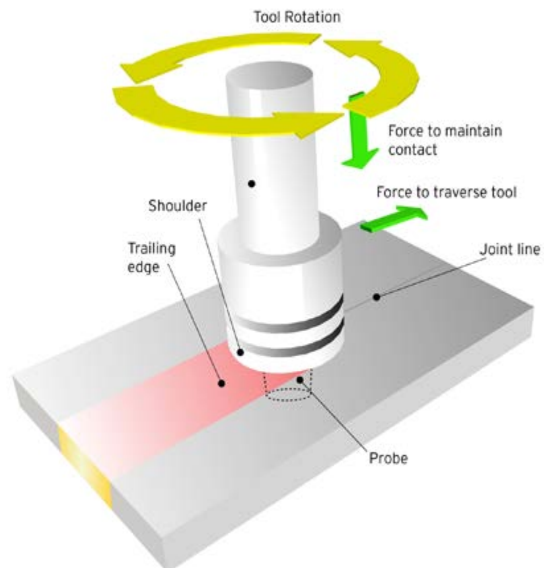

Fig.1 Schematic of Friction Stir Welding [2]

For friction stir welding, a few researchers have worked for diversified aspects using various tool pin profiles to study the influence of pin profiles on properties of resulting FSW joint [10,11]. In FSW joints usually there are four regions, namely, (i) unaffected base metal; (ii) heat effected zone (HAZ); (iii) thermo–mechanically affected zone (TMAZ); and (iv) Friction stir processed (FSP) zone. The formation of above mentioned regions is affected by the material flow behaviour under the action of rotating non consumable tool. At the same time, the material flow behaviour is predominantly influenced by the FSW tool-pin profiles, FSW tool-dimensions and FSW process parameters [10,11].The literature available for study of the effect of tool profiles on FSP zone formation and subsequent effects on peak temperature and flow stress variations for AA6061 aluminium alloy is very limited hence an attempt has been made to understand effect of tool pin profiles on the aforesaid variations using HyperWorks, an efficient FEA tools used for simulation of peak temperature & flow stresses for AA7075-T451 aluminium alloy [12].

ISSN 2348 – 7968

2. MODELING OF VARIOUS TOOL-PIN PROFILES

For conducting the simulation of friction stir welding of two plates of AA6061 of size 381 mm x 127 mm x 5 mm thick, three FSW tools modelled with four pin profiles as (i) Conical (frustum of a cone), (ii) Conical with flutes at 90° interval (iii) Hexagonal prism and (iv) Trapezoidal pin profiles (Figure – 2(i), (ii), (iii) & (iv)) were used. The welding speeds were selected as 4.23 mm/sec, temperature of plate $=20^\circ$c and rotation speed was kept as 600 rpm constant. The tool tilt angle was maintained at 0°. In each weld simulation, the tool plunge was kept constant at 4.7 mm with an axial force of 14 kN.

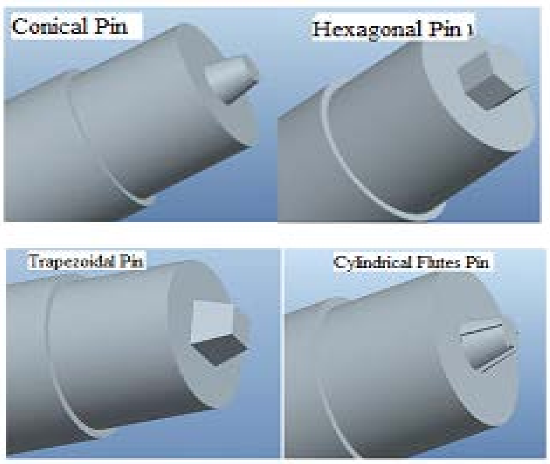

Fig.2. FSW Tools with different Tool-pin Profiles

The material of the tool selected was cold work die steel with 1.8% carbon & 11.8% Cr. The dimensions of the FSW tools used for simulations are shown in figure – 3 (a) & (b):

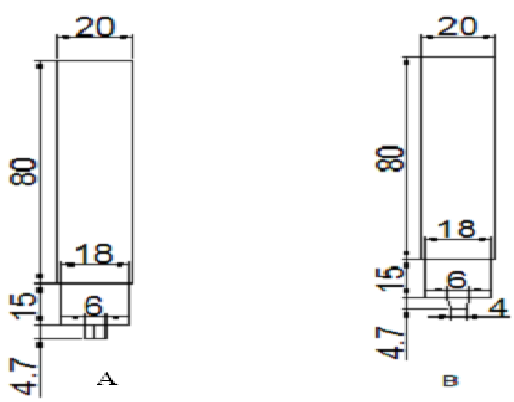

Figure.3 Tool Dimensions (a) With Hexagonal Pin
(b) With Pin as Conical (frustum) & Conical with Flutes at 90°

3. RESULTS OF SIMULATIONS

Following figures (Figures – 4 to 11) show the graphical results of peak temperature and flow stresses induced in AA6061alloy using above mentioned four types of tool-pin profiles keeping the rotational speed as 600 rpm constant at 14 kN axial load & welding speed of 4.23 mm/sec.

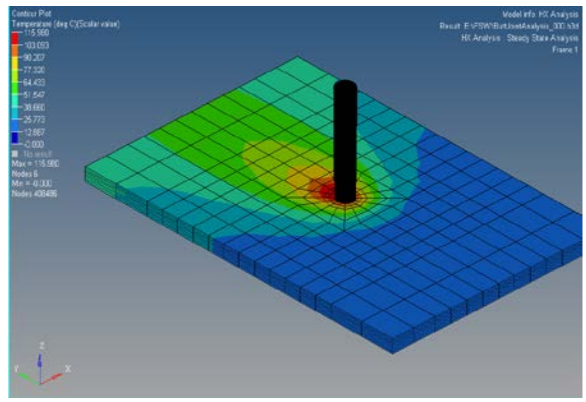

Fig- 4.Temperature distribution using **Conical Pin**

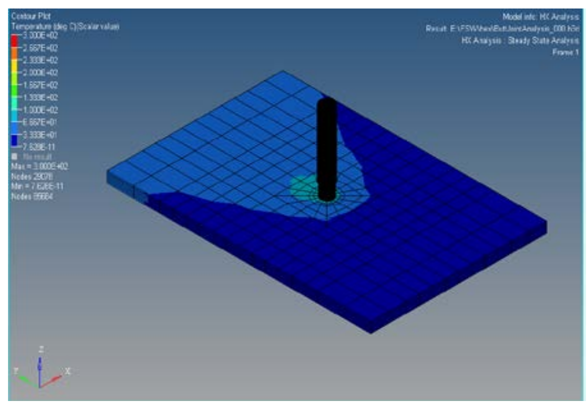

Fig-5.Temperature distribution using **Hexagonal Pin**

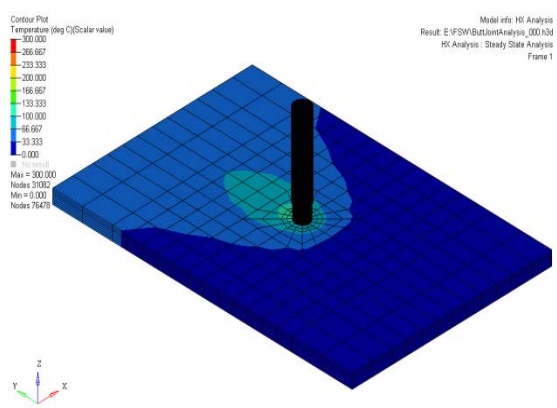

Fig-6.Temperature distribution using **Trapezoidal Pin**

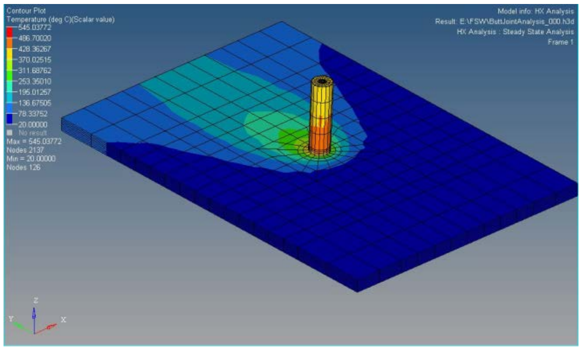

Fig-7.Temperature distribution using **Cylindrical Pin**

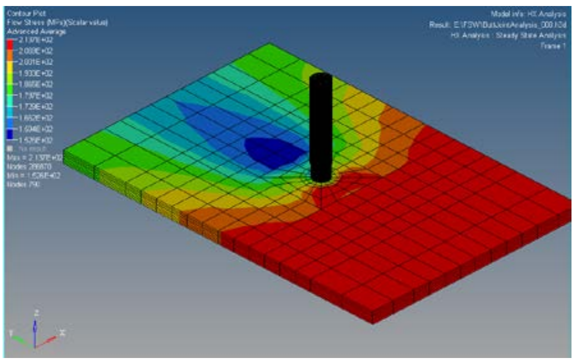

Fig-8. Flow stress distribution using **Conical Pin**

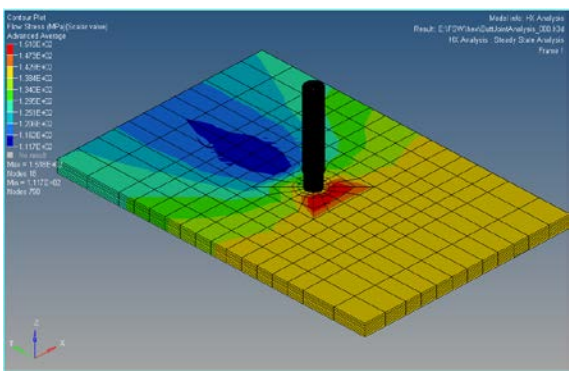

Fig-9. Flow stress distribution using **Hexagonal Pin**

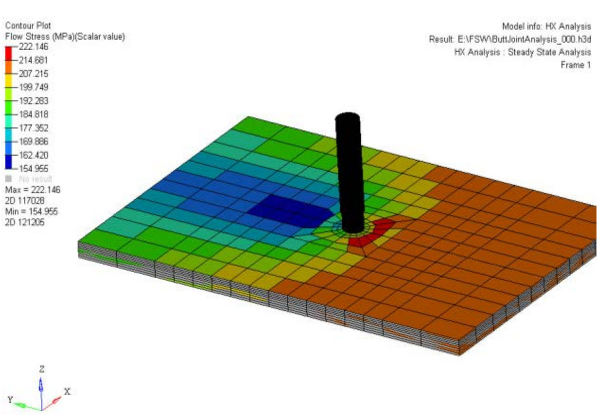

Fig-10. Flow stress distribution using **Trapezoidal Pin**

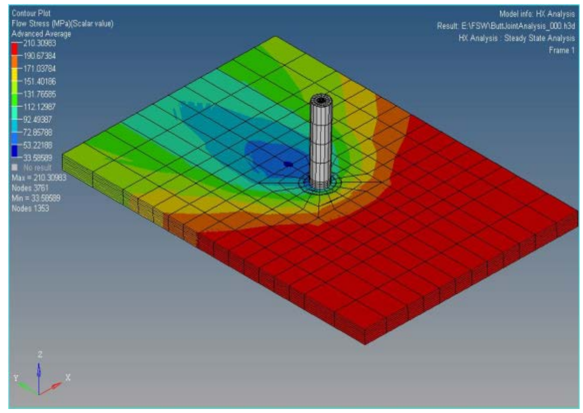

Fig-11. Flow stress distribution using **Cylindrical Pin**

Results of simulation in HyperWorks manufacturing solution module for four different tool-pin profiles, peak temperatures and flow stresses obtained for AA6061 aluminium alloy are summarized in Table – 1.

Table – 1 Recorded Results of Simulations for Four Tool-pin Profiles

Pin Profile*	Pressure (MPa)	Peak Temperature (°C)	Flow Stress (MPa)
1	879.0	115.98	213.0
2	625.9	300.0	151.8
3	881.6	300.0	222.1
4	411.37	545.03	210.30

*1=Conical pin profile, 2=Hexagonal pin profile, 3=Trapezoidal pin profile, 4=Cylindrical pin profile.

4. CONCLUSIONS

The following conclusions are arrived at from the investigations made from the results of simulations for four different tool-pin profiles.

1. During the simulation it is found that comparatively low peak temperature of 300°C provides minimum flow stress of 151.8MPa for Hexagonal pin profile as compared to cylindrical pin profile.
2. The peak temperature of ~545°C is achieved for cylindrical pin profile with moderately high flow stresses (~210MPa).

3. Similarly, the least peak temperature is observed as ~115°C with still further higher flow stress value of 213MPa.
4. For trapezoidal pin profile, the flow stresses are highest even at a low peak temperature of 300°C which is achieved for hexagonal pin profile too.

Thus, it can be concluded that hexagonal pin profile provides better flow of material particles with least resistance amongst all other pin profiles.

In future the optimization of process parameters can be carried out for the selected geometries of tool-pin profile by performing DOE study using Hyperstudy tool. With the help of this work best tool geometry can be suggested for getting the best weld quality with optimum parameters for selected aluminum alloy & FSW tool material in general.

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