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Modelling of FSW Tools and Simulation of Viscosity & Flow Stress during Friction Stir Welding of Aluminum Alloy AA6061

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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 aluminum 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 along with simulation of viscosity 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 modelled and results are presented for variations in viscosity of aluminum alloy plate as well as flow stresses generated at and around the tool pin during the welding process.**

Index Terms— **Modelling of FSW Tools, Simulation, Viscosity, Flow Stress, AA6061**

I. 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.

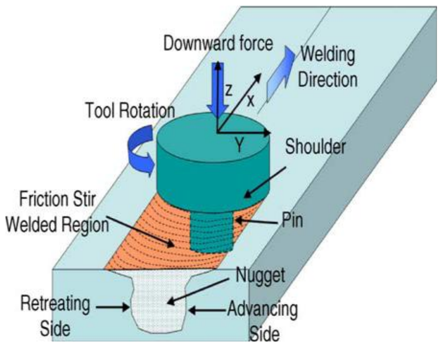
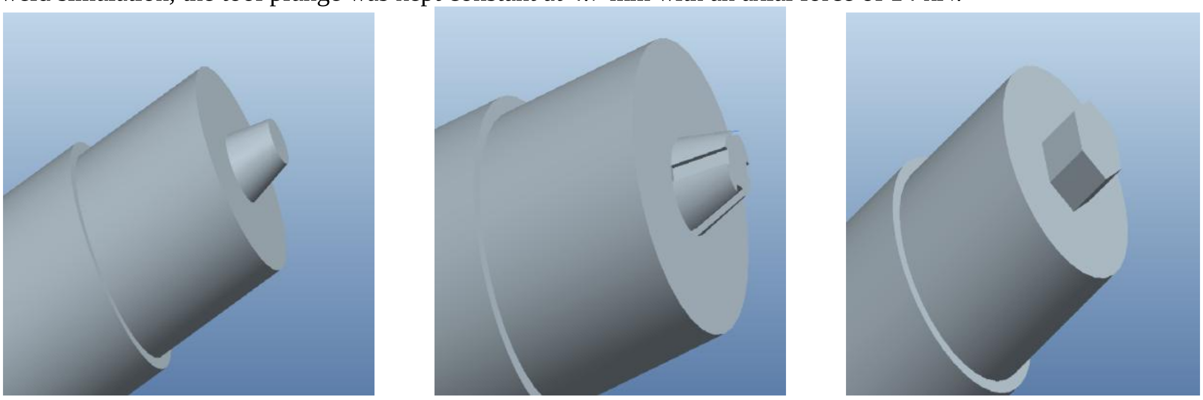


Fig – 1 Schematic of Friction Stir Welding [2]

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]. Sato et al. [4] investigated the transverse tensile properties of the friction stir weld of 6063-T5 aluminum. Effect of FSW parameters on tensile properties of 2024Al-T4 has been studied and ductility found to increase with increasing tool rotation rate by Biallas et al. [5]. A. von Strombeck et al. [6] provided variation of tensile properties at different locations of FSW joints of 7075Al alloy & concluded that strength is almost constant in the nugget zone & the lowest strength is observed in HAZ. R.S. Mishra et al. [7] evaluated the fatigue behavior of FSW welds, including stress-number of cycles to fatigue (S-N) behavior & fatigue crack propagation behavior. Establishment of empirical relationships to predict grain size and tensile strength of friction stir welded AA 6061-T6 aluminum alloy joints and prediction of tensile strength, hardness and corrosion rate of friction stir welded AA6061-T6 Aluminum alloy joints have been due to S. Rajkumar et al. [8, 9]. 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 behavior under the action of rotating non consumable tool, but development of these zones & their corresponding microstructures affect mechanical properties to a great extent. At the same time, the material flow behavior is predominantly influenced by the FSW tool-pin profiles, FSW tool-dimensions and FSW process parameters [10,11].Also, an attempt has been made for simulation of peak temperature & flow stresses for AA7075-T451 aluminum alloy by K.D. Bhatt et al. [12]. The literature available for study of the effect of tool profiles on FSP zone formation and subsequent effects on viscosity and flow stress variations for AA 6061 aluminum alloy is very limited, Nandan R. et al. [13] have simulated spatial variation of viscosity in AA6061 along the thickness of plates & observed that there is no significant flow when viscosity is higher than about 5 x 10^6 Pa-s. Effects of rotational speed & tool-pin design on defect formation in friction stir processing of AA2219 have been carried out by Elangovan et al [14] & gave conclusion that tool design & welding parameters affect material flow patterns. In the present work, an attempt has been made to understand effect of tool pin profiles on the variations of viscosity & flow stresses by simulation using Hyper Works, an efficient FEA tools used.

II. EXPERIMENTAL WORK

For conducting the simulation of friction stir welding of two plates of AA6061 of size 300 mm x 150 mm x 5 mm thk, three FSW tools modeled with three pin profiles as (i) Conical (frustum of a cone), (ii) conical with flutes at 90^0 interval and (iii) hexagonal prism were used (Figure – 2(i), (ii) & (iii)). The welding speeds were selected as 50, 62 & 70 mm/sec and rotation speed was kept as 1600 rpm constant. The tool tilt angle was maintained at 0^0. In each weld simulation, the tool plunge was kept constant at 4.7 mm with an axial force of 14 kN.



(i) Tool Pin Profile of Frustum of a cone (conical) **(ii) Tool Pin Profile with Flutes on Conical pin** **(iii) Hexagonal Tool Pin Profile**

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):

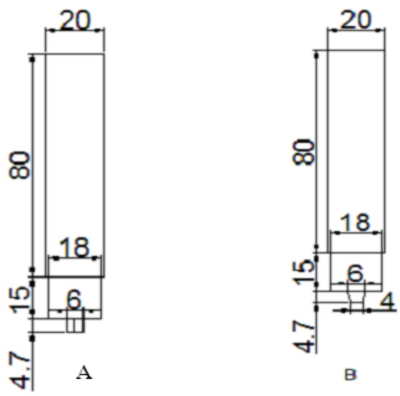


Fig – 3 Tool Dimensions (A) With Hexagonal Pin (B) With Pin as Conical (frustum) & Conical with Flutes at 90^0

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III. RESULTS OF SIMULATIONS

Following figures (Figures – 4 to 9) show the graphical results of flow stresses and viscosity induced in alloy 6061 using hexagonal prism type pin-tool keeping the rotational speed as 1600 rpm constant at 14 kN axial load & welding speed of 50, 62 & 70 mm/sec.

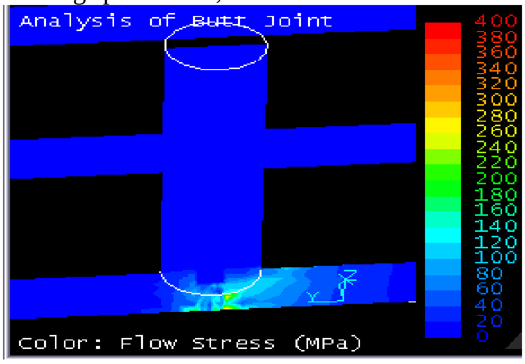

Fig – 4 Flow stress at 50 mm/sec Using Hexagonal pin-tool

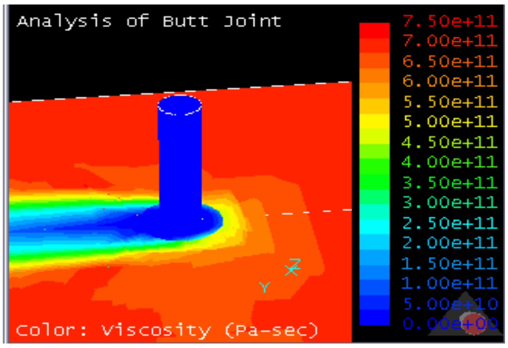

Fig – 5 Viscosity at 50 mm/sec Using Hexagonal pin-tool

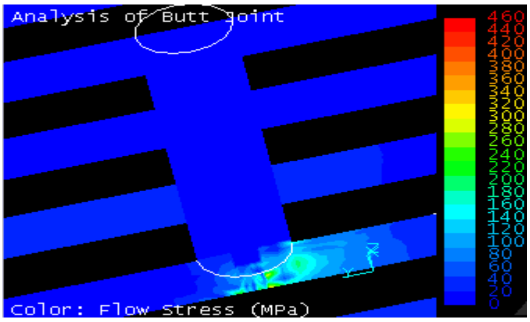

Fig – 6 Flow stress at 62 mm/sec Using Hexagonal pin-tool

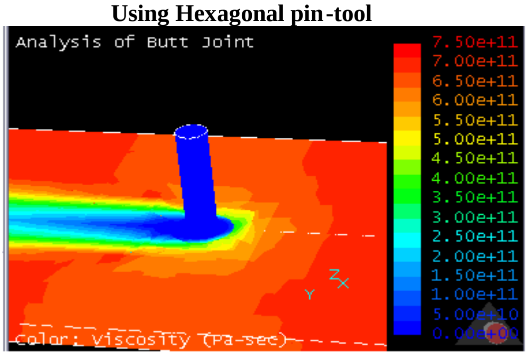

Fig – 7 Viscosity at 62 mm/sec Using Hexagonal pin-tool

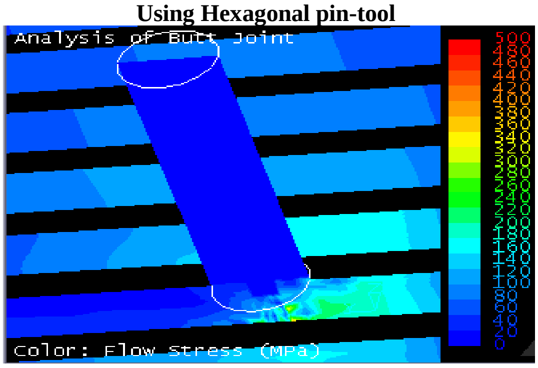

Fig – 8 Flow stress at 70 mm/sec Using Hexagonal pin-tool

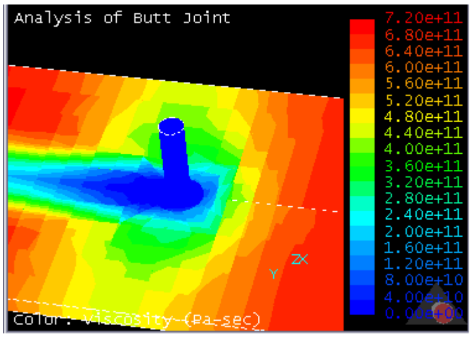

Fig – 9 Viscosity at 70 mm/sec Using Hexagonal pin-tool

Results of simulations of flow stresses & viscosity for the same alloy using Conical (frustum) and Conical Fluted pin-tools at 1600 rpm & 14 kN and various welding speed can be obtained in similar way the results of which are mentioned in the table – 1.

Table – 1 Recorded Results of Simulations for Three Pin-tool Profiles

Experiment No.	Pin Profile used	Welding Speed (mm/sec)	Rotational Speed (RPM)	Axial Force (kN)	Viscosity (Pa-sec)	Flow Stress (MPa)
1	Hexagonal prism	50	1600	14	6.13×10^{11}	400
2	Hexagonal prism	62	1600	14	6.48×10^{11}	460
3	Hexagonal prism	70	1600	14	6.59×10^{11}	500
4	Conical	62	1600	14	7.10×10^{11}	548

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	(Frustum)					
5	Fluted Conical (Frustum)	70	1600	14	7.20×10^{11}	563

IV. CONCLSION

The following conclusions are arrived at from the investigations made:

1. The joint fabricated using hexagonal prism shaped pin profile at welding speed of 50 mm/sec has of viscosity & flow stresses lower as compared to those obtained at 62 mm/sec and 70 mm/sec. Also, the joint produced by using conical (with & without flutes) pin profile showed an increase of these two parameters. Thus, for the same rotational speed & welding speed, the *pin profile has significant effect on behaviour of the FSW joint* produced between plates of aluminum alloys AA6061.
2. The hexagonal prism profile of pin-tool indicates a higher *peak temperature* resulting in a lower viscosity & flow stresses.
3. Similarly, the joint fabricated (simulated) by using conical pin (with or without flutes) profile with welding speed of 62 mm/sec and 70 mm/sec exhibit further increase in the same two parameters. Thus, *increase in welding speed results in increase in viscosity & flow stresses.*
4. Changing the *pin-tool profile also has significant effect on temperature* generated and can be anticipated from viscosity as well as flow stresses induced during FSW of AA6061 plates.

The simulations of viscosity & flow stresses can be validated by extending the virtual experiment to physical experiment on milling machine or VMC using the FSW parameters mentioned in table – 1. Along with this an arrangement for direct measurement of temperatures during FSW can also be made for cross verification.

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