ANALYSIS OF PEAK TEMPERATURE AND FLOW STRESS IN FRICTION-STIR WELDING THROUGH SIMULATION

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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 the welding of high strength materials such as aluminum alloy, steel alloy, titanium alloy etc. which are difficult to weld by conventional fusion welding techniques. The FSW process parameters such as tool rotational speed, welding speed, axial force, and tool pin profile, etc... Play an important role in deciding the weld joint quality. In this research work, the simulation study has been carried out to observe the effects of rotational speed and traverse speed on output variables like peak temperature and flow stress for aluminum alloy 6061. Both the output variables affect the microstructure and weld quality. Hence, both the output variables need to be analyzed. For this purpose, five levels for each parameter (Rotational speed, Traverse speed) have been selected. Non linear thermal simulations have been carried out using FEA software called Hyperworks.

***Keywords*: FSW, Peak Temperature, Flow Stress, Simulation, Hyperworks**

I INTRODUCTION

Friction stir welding (FSW) is a solid-state joining technique which was invented at The Welding Institute (TWI), UK, in 1991. The FSW has been found to be effective for joining hard-to-weld metals and for joining plates with different thickness or different materials. In the FSW process a non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of work pieces to be joined and traversed along the line of the joint as shown in fig. 1. As the tool travels, heat is generated by the contact friction between the shoulder and the work piece, and by the plastic deformation of the materials in the stir zone. The high strain and heat energies experienced by the base metal during stirring causes dynamic recrystallization, which is the formation of new grains in the weld zone. FSW is often a preferred joining technique not only for aluminum alloys but also for other difficult-to-weld metals such as magnesium alloys, titanium alloys and metal-matrix composites, etc. The technique is now widely used in many industrial sectors such as marine, aerospace, railway, land transportation, etc. The behavior of the FSW joints is not only influenced by the geometry of the tools and the joints but also by different process parameters. Numerical analysis has found widespread applications in FSW [1]. Significant progress has been made in the fundamental understanding of both the FSW process and the properties of the resulting welded joints. The heat generated during the process raises the temperature initially at the contact of the tool and work-piece to an extent capable of lowering the material flow stresses which in turn improve plastic flow of work-piece material along the interface. The temperature rise and its distribution in the weld zones become responsible for evolution of the microstructure within the weld that includes grain size, grain boundary character, coarsening and dissolution of precipitates and resulting mechanical properties of the welds when the FSW produces tremendous plastic deformation around the tool and friction between tool and work piece[2]. It, therefore, becomes necessary to obtain information regarding temperature distribution and flow behavior during FSW.

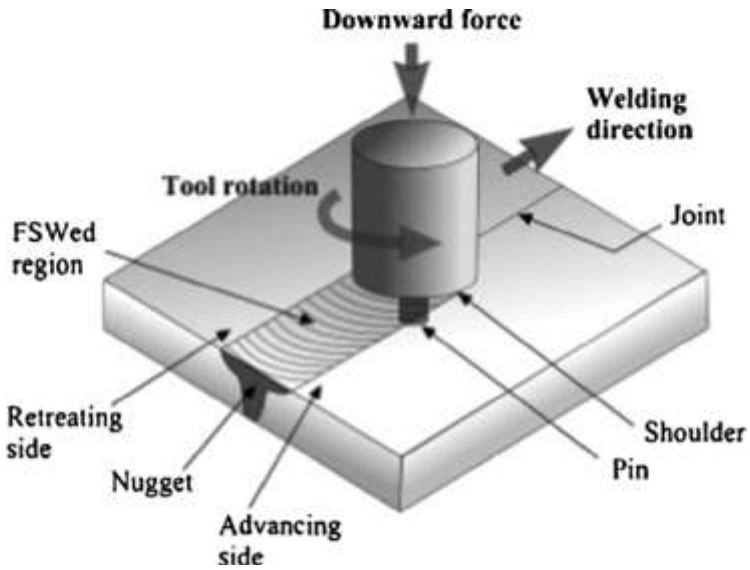

Fig. 1 Principle of the friction stir welding process

II KEY BENEFITS OF FSW

The FSW process (as all friction welding of metals) is the solid state welding process as the metal does not reach to its melting temperature. So there are fewer defects caused due to the melting and solidification of the metal. Other advantages are as follows:

- Low distortion of work pieces.
- Good dimensional stability and repeatability.
- No shielding gas is required.
- No surface cleaning is required.
- No loss of alloying elements.
- Fine microstructure.

- Can be operated in all positions as there is no weld pool.
- Energy efficient.

There are many disadvantages in the welding techniques where the metal is heated to its melting temperatures and let it solidify to form the joint. The melting and solidification causes the mechanical properties of the weld in some cases to deteriorate such as low tensile strength, fatigue strength and ductility. The disadvantages also include porosity, oxidation, micro segregation, hot cracking and other micro structural defects in the joint. The process also limits the combination of the metals that can be joined because of the different thermal coefficients of expansion. As the metal in solid state welding does not reach to its melting temperatures, there are fewer defects caused due to the melting and solidification of the metal. In solid state welding the metals being joined retain their original properties as melting does not occur in the joint and the heat affected zone (HAZ) is also very small compared to fusion welding techniques where most of the deterioration of the strength and ductility begins. Dissimilar metals can be joined with ease compared to fusion welding [3].

III EXPERIMENTAL WORK

3.1. Material selection for tool & work piece

Tool steel is the most common tool material used in friction stirring. This is because a majority of the published FSW literature is on aluminum alloys, which are easily friction stirred with tool steels. The advantages to using tool steel as friction stir tooling material include easy availability and machinability, low cost, and established material characteristics. AISI H13 is a chromium-molybdenum hot-worked air hardening steel and is known for good elevated-temperature strength, thermal fatigue resistance, and wear resistance. In addition to friction stir welding aluminum alloys, H13 tools have been used to friction stir weld both oxygen-free copper (Cu-OF) and phosphorus-deoxidized copper with high residual phosphorus (Cu-DHP) [4]. Due to the foresaid reasons, H-13 has been selected as the tool material. Aluminum alloys (6XXX) are widely used in friction stir welding as a base material because they are heat treatable; they have high corrosion resistance, excellent extrudibility, moderate strength and are available at low cost. And they are most commonly used in building & construction, highway, automotive and marine applications [5].

Aluminum alloy AA6061-T6 plates of size 381 mm x 127 mm x 4 mm with the properties as shown in Table I were selected for the simulations & FSW tool of chromium-molybdenum hot-worked air hardening steel (H-13) with the properties shown in Table II was used to perform virtual FSW using HyperWorks9.0. The tool geometry was selected with cylindrical pin having a shoulder diameter (D), shoulder length (L), pin diameter (d) and pin length (l) of 18mm, 50mm, 6mm and 3.5mm respectively.

Property	Value
Density (kg/m^3)	2700
Specific heat (J/kg-K)	896
Conductivity (W/m-K)	180
Melting temperature (°C)	652
Young modulus (Pa)	4.00E+10
Poisson ratio	0.35

Table – I Physical & thermal properties of AA 6061-T6

Property	Value
Density (kg/m^3)	7870
Specific heat (J/kg-K)	460
X-Conductivity (W/m-K)	24.3
Y-Conductivity (W/m-K)	24.3
Z-Conductivity (W/m-K)	24.3
Young modulus (Pa)	2.10E+11
Poisson ratio	0.35

Table – II Physical & thermal properties of H – 13

3.2. Selection of process parameters

In this research work, Five levels of rotational speed (600, 800,1000,1200,1400 rpm) and traverse speed (60, 80,100,120,140 mm/min) have been selected to study their effects on output variables like peak temperature and flow stress with the help of simulations.

Variables	Levels				
	1	2	3	4	5
Rotational speed (RPM)	600	800	1000	1200	1400
Traverse speed (mm/min)	60	80	100	120	140

Table – III Input parameters and their levels for simulation

IV RESULTS & DISCUSSION

From this research work, it can be found that both the input parameters have significant effects on output variables. It can also be found that as the rotational speed increases and traverse speed decreases, the value of peak temperature increases as shown in fig. 4 and hence the value of flow stress decreases as shown in fig. 5, as the material will flow in a better way at higher temperature. The maximum peak temperature (648°C) and minimum flow stress (48 MPa) is obtained at 1200 rpm and 60 mm/min as shown in table IV. For the rotational speed of 1400 rpm, the software didn't give the converged solution. So the results from Sr. no. 21-25 can't be considered in the analysis. Fig. 2 shows the result of peak temperature generated in hyperworks 11.0 for 1200 rpm of rotational speed and 60 mm/min of traverse speed. The result shows that the maximum peak temperature is generated around the pin i.e. 611 to 685°C. So, the average value of peak temperature has been considered here i.e. 648°C. And the region for the maximum peak temperature and minimum flow stress is same. So the flow stress has also been observed in similar way as shown in fig. 3.

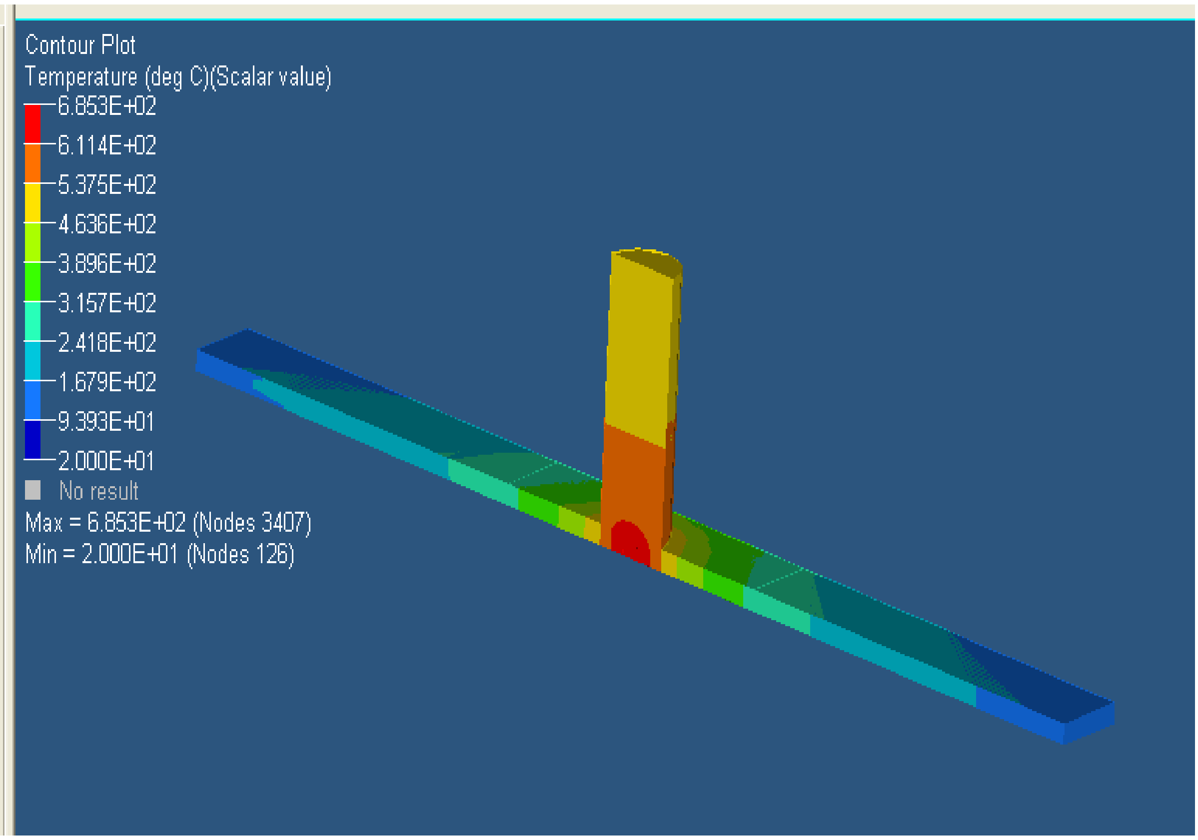

Fig. 2 Result of peak temperature generated in Hyperworks 11.0

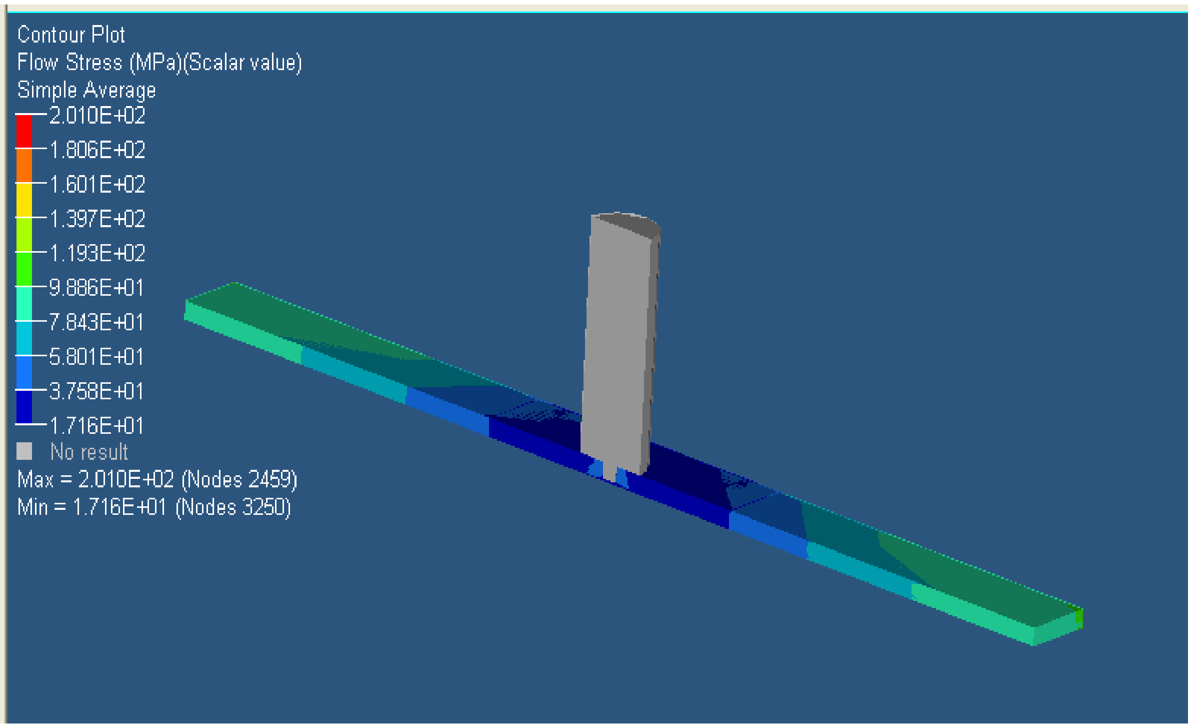

Fig. 3 Result of flow stress generated in Hyperworks 11.0

Sr. no.	RS (RPM)	TS (mm/min)	Peak temp. (˚C)	Flow stress (Mpa)
1	600	60	489.5	63.5
2		80	479	65.5
3		100	470.5	67
4		120	464	68.5
5		140	458	69.5
6	800	60	551	56.5
7		80	541	58.5
8		100	532.5	60
9		120	525	61
10		140	519	62
11	1000	60	602	52
12		80	592.5	54
13		100	583	55.5
14		120	576	56.5
15		140	569.5	57
16	1200	60	648	48
17		80	632	50.5
18		100	623.5	52.5
19		120	615.5	53.5
20		140	609.5	54
21	1400	60	596.5	52
22		80	636	49.5
23		100	648	50
24		120	644	51.5
25		140	638	52

Table – IV Input parameters and output variables

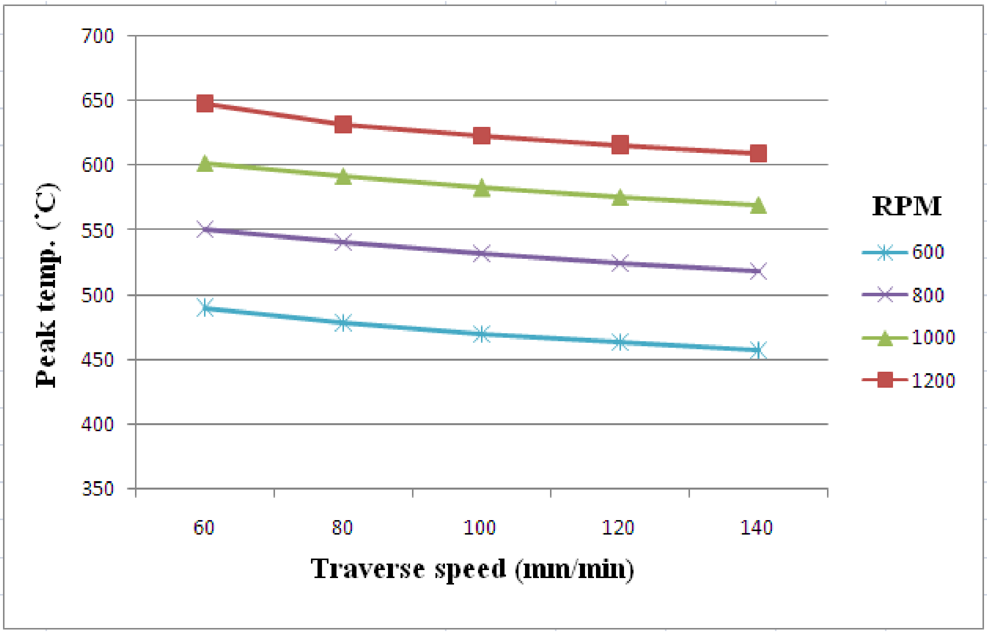

Fig. 4 Graph of peak temperature versus traverse speed

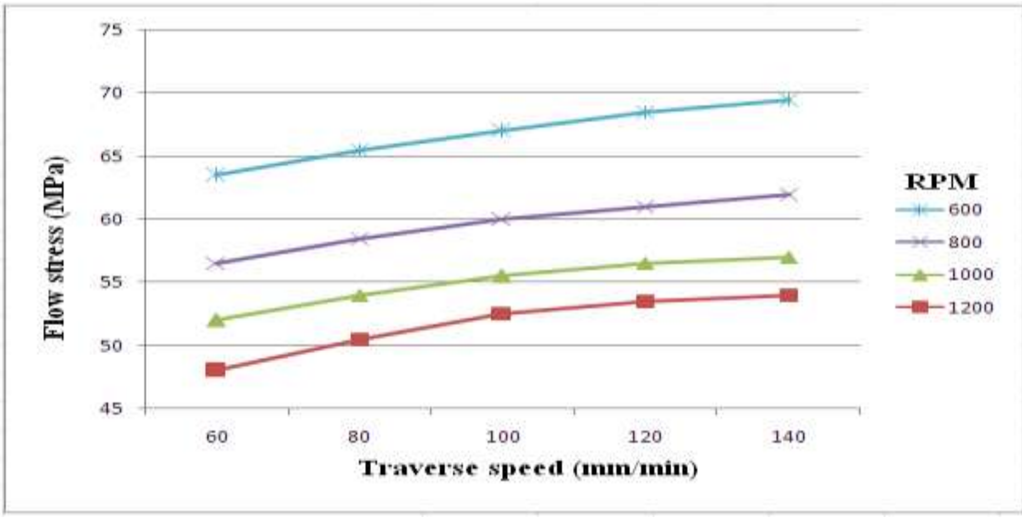

Fig. 5 Graph of flow stress versus traverse speed

V CONCLUSION

From the above results, it can be said that the process parameters such as tool rotational speed and tool traverse speed play an important role in obtaining a specific temperature distribution and subsequent flow stresses within the material being welded, the former controlling the micro structure and in turn, mechanical properties and later, the flow of material which depends up on the peak temperatures obtained during FSW. It can also be said that, the max. Peak temperature and min. flow stress are observed at high rotational speed and low traverse speed. As the peak temperature generated is associated with the microstructure and mechanical properties (Lower temperature can cause the defects like porosity, cracks etc… and if the temperature generated is higher than the melting temperature then it may be the chances of splashing out of the material) and flow stress is associated with the energy consumption (The lower is the flow stress, the lesser is the energy required to carry out the weld) both the output variables need to be analyzed.

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