Investigation of Effect of Process Parameters on Maximum Temperature During Friction Stir Welding of Aluminium Alloy

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Abstract— In case of friction stir welding, the maximum temperature along the weld line within appropriate range at tool workpiece interface is responsible for quality of welded joint. Through this paper, an attempt is made to establish a relationship between the input process parameters and the maximum temperature along the weld line during friction stir welding of aluminium alloy AA-7075. The design of pre-experimental simulation has been performed in accordance with full factorial technique. The simulation of friction stir welding has been performed by varying input parameters, tool rotational speed and welding speed. The analysis of variance (ANOVA) is used to investigate the effect of input parameters on maximum temperature during friction stir welding. A correlation was established between input parameters and maximum temperature by multiple regression lines. This study indicates that the tool rotational speed is the main input parameter that has high statistical influence on maximum temperature along the weld line during friction stir welding of aluminium alloy AA-7075.

Key words: Friction sir welding, Aluminium Alloy, Pre-experimental simulation, Temperature

I. INTRODUCTION

Friction stir welding is based upon the simple concept of heat due to friction. This welding technique is categorised under solid state joining process because the maximum temperature achieved in case of friction stir welding is less than the melting point of the base metal. The joining occurs at the plastic stage of the metal when it is in soft condition at elevated temperatures. The major welding parameters in friction stir welding process are tool rotational speed, welding speed, axial load, tilt of tool pin & geometry of tool because they are responsible for generation of heat at tool workpiece interphase which ultimately effect the weld quality. As the machine of friction stir welding is very costly therefore the researchers and the scholars utilize conventional vertical milling machine for their research work [1]. The conversion of vertical milling machine is generally done by modifying the tool and clamping device. But before going to the experimental work, simulation of the welding process can be performed in order to investigate the maximum temperature due to several welding parameters.

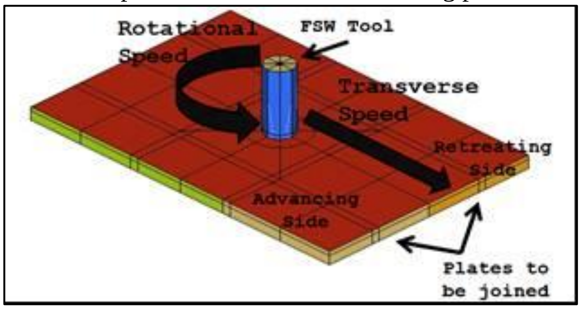


Fig. 1: The schematic model of friction stir welding

In the present work, the effect of two main welding parameters i.e. tool rotational speed (TR) and welding speed (WS) on maximum temperature during friction stir welding of aluminium alloy AA-7075 is studied. The pre-experimental simulations are designed, the virtual experiments are conducted on the simulation tool HyperWorks®. The data obtained by simulation is analysed by using the commercial software Minitab®. The Anova was used to investigate the influence of tool rotational speed and welding speed on maximum temperature during friction stir welding process. All other parameters such as tool geometry and friction force were kept constant.

II. LITERATURE REVIEW

Z. Zhang & H. W. Zhang [2] worked on a fully coupled thermo-mechanical model for friction stir welding. They reported that acceleration of material flow near the top surface depends upon the rotation of shoulder. They showed that temperature distribution in the friction stir welding process is symmetrical along the weld line. Hongjun Li and Di Liu [3] worked on simplified thermo-mechanical modeling of friction stir welding with a sequential FE method. They presented a methodology for modeling the transient thermal and mechanical responses without computing the heat generated by friction or plastic deformation. Through this thermal model, they showed temperature history and they found it good agreement with experimentally measured results. Z Feng et. al.,[4] used an integrated thermal-metallurgical-mechanical model to study the formation of the residual stress in Al6061-T6 friction stir welds. K. N. Salloomi et. al., [5] worked on 3-Dimensional nonlinear finite element analysis of both thermal and mechanical response of friction stir welded 2024-T3 aluminium plates. They used Ansys to predict thermal behaviour and thermal stresses. They found considered the effects of various heat transfer conditions at the bottom surface of the workpiece, thermal contact conductances at the work-piece and the backing plate interface on the thermal profile. Abdul Arif, et.al, [6] worked on FEM for validation of maximum temperature in friction stir welding of aluminium alloy. The developed finite element model and validated it by comparing the results with obtained by Feng et al. aluminium alloy. Armansyah et.al. [7] worked on temperature distribution in friction stir welding using finite element method by using hyperworks. They analysed heat affected zone and found that the peak temperature of friction stir welding appeared in rear of the advancing side. Binnur Gören Kiral et.al. [8] worked on finite element modeling of friction stir welding in aluminum alloys joint. They performed transient thermal finite element analyses are in order to obtain the temperature distribution in the welded aluminium plate during FSW. They analysed temperature distribution by using ansys and hyperworks. Zhang, Z., and H. W. Zhang [9] studied numerically the effect of transverse speed in friction stir welding. They analysed the effect of transverse speed on friction stir welding by using a fully coupled thermo-mechanical model. They observed that when the transverse speed was higher, the stirring effect of the welding tool became weaker which is also the reason for the occurrence of weld flaw.

III. MATERIAL SELECTION

Aluminium alloy AA-7075 is generally used in transport applications, including marine, automotive and aviation, due to their high strength-to-density ratio. The properties of AA7075 are shown in Table I.

Property	Values
Density	2.81g/cm3
Melting Point	477-635ºC
Modulus of Elasticity	71.7GPa
Poisons Ratio	0.33
Thermal Conductivity	130 W/m-k
Specific Heat Capacity	0.96 J/g ºC

TABLE I: PHYSICAL & THERMAL PROPERTIES OF AA-7075

Finite element analysis was performed by using of HyperWorks® simulation tool. A three dimensional finite element model for butt joint of aluminium plates was developed as shown in figure 2. Two plates of aluminium alloy 7075 size 300mm×200mm×3.1mm is considered with steel tool H-13 of shoulder diameter, shoulder length, pin diameter and pin length 16mm, 150mm, 4mm & 2.79mm respectively. The dimensions are selected with reference to the available literature for valid combinations.

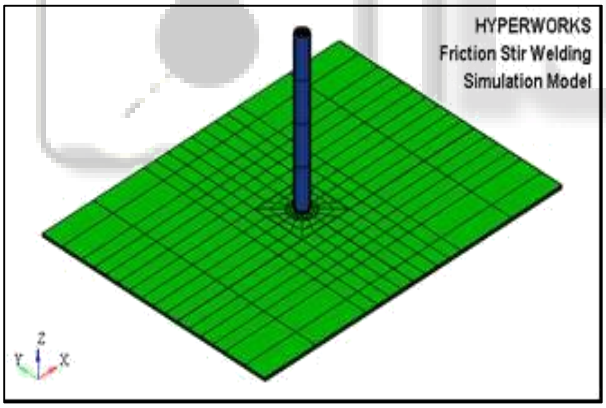


Fig. 2: Isometric view of finite element model of friction stir welding process showing tool and workpiece.

IV. DESIGN OF SIMULATION RUNS

Full Factor approach investigates all possible combinations, maximizing the possibility of finding a favourable result. For a full factorial design, The number of possible designs is N = Lm where L = number of levels for each factor, m = number of factors. [10] The important process parameters of FSW that were considered in the pre-experimental simulation were welding speed and tool rotation. Other parameters like axial force and tool geometry were kept constant. Three levels were chosen for each parameter. The number of process parameters and their corresponding levels are shown in Table II.

S.No	Parameter	Level I	Level II	Level III
1	Tool Rotation (TR)	300	375	450
2	Welding Speed (WS)	2.50	3.75	5.00

Table II: Parameters and their level

According to full factor approach nine pre-experimental simulations were planned. The model of full factorial is shown in Table III.

Designation	TR (RPM)	WS (mm/s)
S1	300	2.50
S2	300	3.75
S3	300	5.00
S4	375	2.50
S5	375	3.75
S6	375	5.00
S7	450	2.50
S8	450	3.75
S9	450	5.00

Table III: Combination of pre-experimental simulation

V. SIMULATION PROCEDURE

HyperWorks® simulation tool is used for the simulation or finite element analysis. The steps for finite element analysis of friction stir welding process are as below.

1) Loading of FSW User profile
2) Selection of Units
3) Creation of butt weld model
4) Loading of model to solver
5) Inspection of materials and process parameters
6) Running the analysis
7) Post process results obtained in hyperview [11]

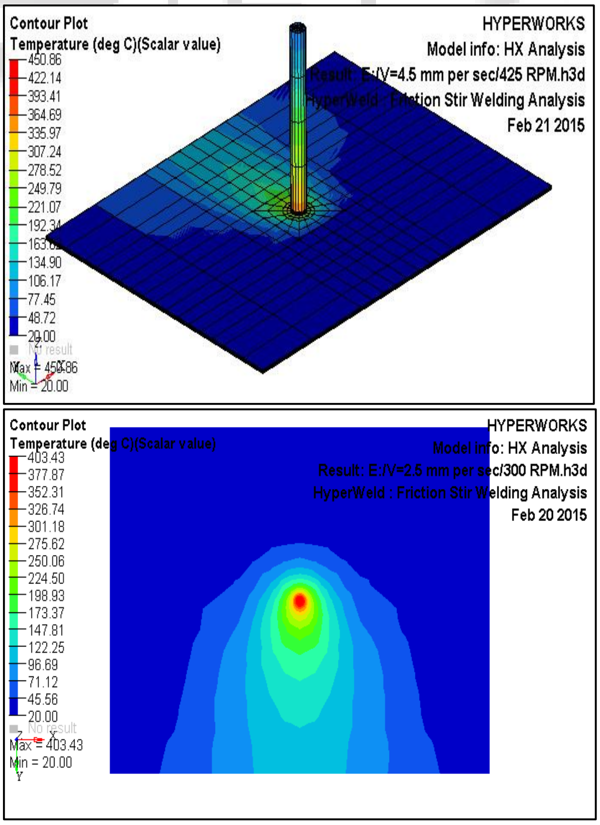


Fig. 3: Isometric view and top view of simulated model of friction stir welding process showing temperature contours from minimum (blue) to maximum (red) values.

As the friction stir welding process is a solid state joining process, so the maximum temperature achieved must be less than the solidus temperature of the workpiece material as reported by several researchers and authors. Table IV. shows the temperature values of obtained by pre-experimental simulations are within the limits of the maximum temperature in friction stir welding.

Designation	TR (rpm)	WS (mm/s)	Temp
S1	300	2.50	403.43
S2	300	3.75	395.96
S3	300	5.00	391.78
S4	375	2.50	442.27
S5	375	3.75	432.92
S6	375	5.00	427.13
S7	450	2.50	476.72
S8	450	3.75	465.75
S9	450	5.00	458.43

Table IV: Temperature results pre-experimental simulation as per designed combinations of parameters

VI. RESULTS AND DISCUSSSION

A. *Effect of Welding Parameters on Maximum Temperature Along The Weldline:*

In friction stir welding, the quality of weld depends upon the maximum temperature along the weldline. As far as effect of welding parameters on maximum temperature is concerned, the observations are done on the basis of plots for the data obtained from pre-experimental simulation of the welding process. The main effect & interaction plots are obtained by software based statistical tool Minitab [12]. Figure 5 shows the main effect or the individual effect of tool rotational speed (TR) and welding speed (WS) on the maximum temperature along the weldline during friction stir welding and it is observed that the temperature increases with increase in tool rotational speed where as it decreases with the increase in temperature. Figure 6 shows the interaction or combined effect of tool rotation (TR) and welding speed (WS) on the temperature.

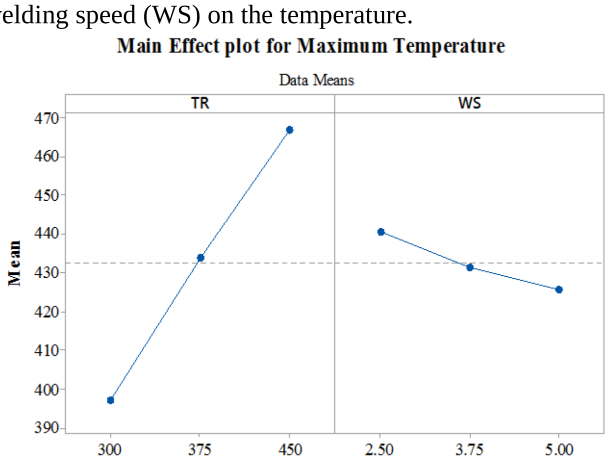


Fig. 4: Graphical representation of main effect of Tool rotational speed (TR) and Welding speed (WS) on Maximum Temperature during friction stir welding of Aluminium Alloy AA-7075.

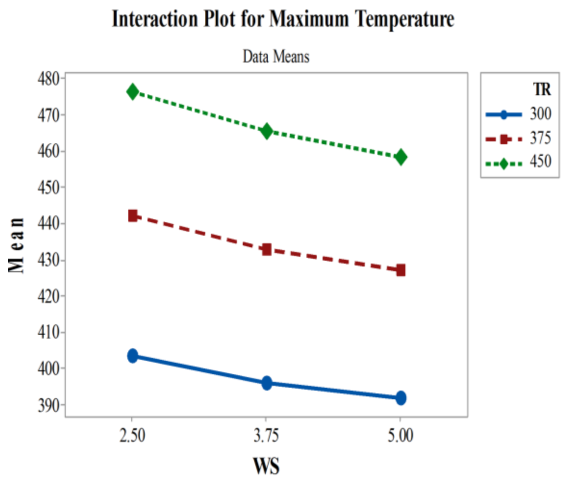


Fig. 5: Graphical representation of Interaction effect of Tool rotational speed (TR) and Welding speed (WS) on Maximum Temperature during friction stir welding of Aluminium Alloy AA-7075.

B. *Statistical Analysis:*

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	2	7669.81	3834.91	886.79	0.000
TR	1	7331.11	7331.11	1695.26	0.000
WS	1	338.70	338.70	78.32	0.000
Error	6	25.95	4.32		
Total	8	7695.76			

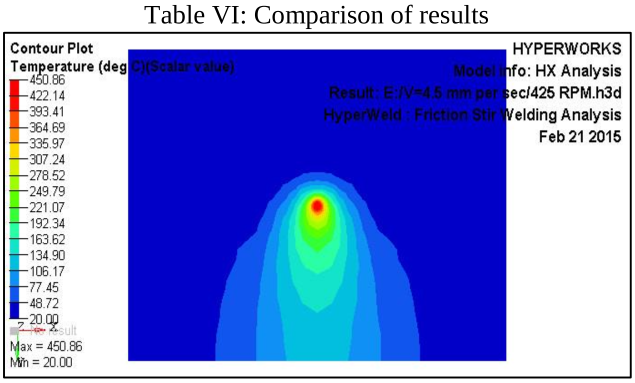
Table V: Anova for temperature

The correlation between the factors such as tool rotational speed (TR), welding speed (WS) and the maximum temperature (TEMP) during friction stir welding of aluminium alloys 7075 are obtained by multiple linear regressions. The empirical relations obtained by regression analysis give fairly good results within the range of TR of 300-450 rpm and weld speed of 2.5-5.0 mm/s. The equation or regression model obtained is as follows:

TEMP = 280.47 + 0.4661 TR - 6.011 WS.........(R^2=99.6)

Output Parameter	Simulation Result	Regression Model Result	Error (%)
Max. Temp (°C)	450.86	442.87	1.77

Table VI: Comparison of results



In order to validate the regression model, a FSW simulation trial was carried out with TR of 425 rpm and WS of 4.5 mm/s. The values obtained by regression model and trial simulation are compared as shown in table 6, it is observed that the pre-experimental simulation result shows the variation of 1.77 %.

VII. CONCLUSIONS

The weld quality of friction stir welded joint highly depends upon the maximum temperature achieved along the weldline during the process because at high temperatures within the limit, stirring action of tool is improved due to softening of workpiece. From the investigation it is found that increase in tool rotational speed TR increases the temperature because the process time increases resulting in generation of more frictional heat at the tool workpiece interphase. It is also found that increase in welding speed decreases the temperature because of relatively less process time and generation of less frictional heat. The simulation with TR of 450 rpm and WS of 5 mm/s showed the maximum value of temperature, while the simulation with TR of 300 rpm and WS of 2.5 mm/s achieved minimum temperature along the weldline during friction stir welding of aluminium alloy AA-7075. From the ANOVA, it is concluded that tool rotational speed is the main input parameter that has high statistical influence on maximum temperature during friction stir welding process. Regression model developed in this investigation could be used for real time prediction of maximum temperature for various tool rotational speed and welding speed without requiring experimental testing.

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