Thermomechanical Modeling of Friction Stir Welding for Different Material using Altair's HyperWeld FSW

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***Abstract*- Friction stir welding (FSW) is a solid state welding process which involves the joining of two similar or dissimilar materials without the application of filler material. The tool performs the three steps to complete the welding process which are Plunge, Dwell and Translation. During the plunge stage the tool penetrates into the workpiece material and then translates onto the weld line. In between the translation motion tool moves in forward direction and behind that the workpiece material mixed into each other and form weld.**

In this paper study, Friction stir welding is a nonlinear thermal process which is simulate with the help of using Altair's HyperWeld. It is foremost computer-aided engineering (CAE) application which used in simulation purpose. Using different materials with different input parameters the butt joint is created. In this study the different materials are used such as AA7075, AA6061, and AA2219 for various process parameters. The process parameters are (1) Rotational speed are 600 rpm, 1000 rpm and 1400 rpm, (2) Tool translational speed are 100 mm/min, 150mm/min and 200 mm/min and (3) Tool shoulder diameter are 12 mm, 18 mm and 24mm. With the help of these different process and geometrical parameters the thermal distribution result is analyzed. The results are presented for dissimilarity in peak temperature of three different aluminum alloy plate at the same input parameters during the Friction Stir Welding process.

Keywords- Thermal Analysis; Friction Stir Welding; Aluminum Alloy; Peak Temperature.

I. INTRODUCTION

Friction stir welding is a recent welding technology developed in 1991 at TWI of UK [6]. In this process a non consumable tool utilized having a shoulder and a small pin projecting from it. Amongst the emerging new welding technologies, this friction stir welding (FSW) process is used mostly for welding of high strength aluminum alloys because these alloys are difficult to weld by other conventional fusion welding techniques. Again main advantage of this FSW process is that, it is an environmentally beneficial welding process because it doesn't produce any fumes and spatter which are harmful to our body and environment also. The whole FSW process carryout in three steps i.e. Plunge, Dwell and Translation. During the first stage of friction stir welding process the tool is rotated and it is simultaneously plunged into the weld line of two plates. This stage is called as Plunge stage; in that the tool front projected area called as pin is penetrate into the workpiece. During that penetration pin side, tip and shoulder surface makes frictional contact with the workpiece material and generates heat. Due to heat generation, the contact material between the tool, and workpiece get molten and tool easily penetrate into the workpiece. After the plunge stage, tool only rotates at same plunged area for a small period of time so that proper amount of heat generation take place which is most important for the conversion of hard material into soften material and this stage is called as Dwell stage. When required amount of heat generation take place then the tool traversed along the weld line. The frictional heat generation take place due to rubbing of shoulder on work piece material and results in plastic deformation and movement of material from advancing side to retreating side followed by formation of joint behind the tool, this is the last stage of FSW process called as Translational stage. The complete working model as shown in Fig.1.After that tool can be remove from the weld line but there is only one disadvantages of FSW process is that when tool remove from welding material then the pin hole is left in welding line at the end.

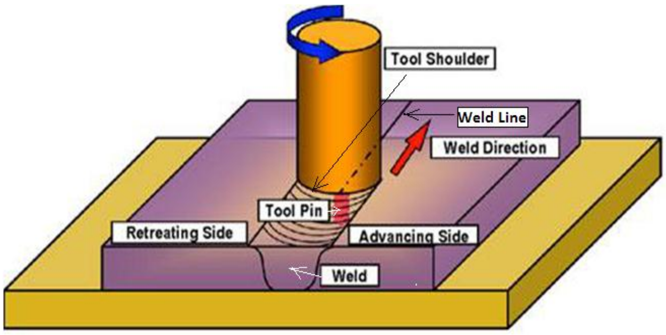

Fig. 1. FSW Process

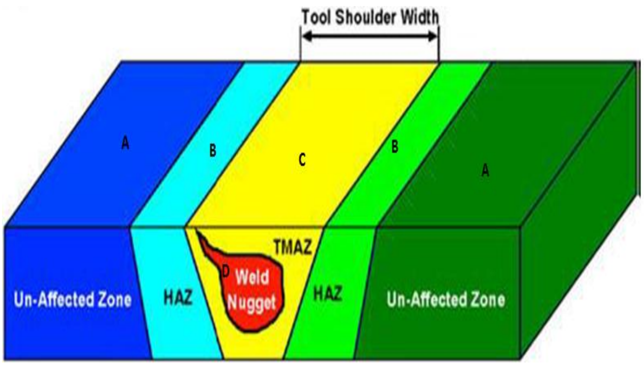

Fig. 2. Microstructure region

The friction stir welding results plays important role to change in typical mechanical properties such as ductility, fatigue, fracture, toughness, and strength of the joint formed which is less in conventional welding process as compare to FSW. During process usually there are four regions created, namely, (i) Heat Affected Zone (HAZ); (ii) Unaffected Base Metal; (Iii) Thermo-Mechanically Affected Zone (TMAZ); (Iv) Friction Stir Processed (FSP) zone as shown in Fig.2. The formation of above mentioned regions is directly affected by the peak temperature changes under the action of non consumable rotating tool. At the same time, the peak temperature behavior is mostly affected by the FSW process parameters, FSW tool dimensions and FSW workpiece material.

In the present literature survey it has found from the various researchers conclusion that peak temperature production is depend on the rotational speed as well as translational speed some of these are, Patel *et.al.* [2] Performed FSW simulation for various tool pin profile at constant rotational speed and found that the cylindrical with flute pin profile produce the high peak temperature than conical, hexagonal and trapezoidal shape. Armansyah *et.al.* [3] worked on the temperature distribution in FSW using FEM and found that with increase in travelling speed at constant tool pin shoulder rotational speeds will reduce the amount of heat in weld zone and it directly affects on peak temperature. Dr. Jweeg *et.al.* [11] Worked on the Theoretical and Experimental investigation of transient temperature distribution in friction stir welding of AA7020-T53 and concluded that the obtained peak temperature is 70% of the melting point of parent material and maximum temperature measured at mid position of plate. Patil *et.al.* [5] Have experimented on thermal analysis of Friction Stir Welding of AA7075 using Altair's HyperWeld and seen that the temperature increase with increase in tool rotational speed and also predicted that the temperature at advanced side is higher than retract side. Gautam *et.al.* [1] Have made the study of peak temperature in friction stir welded T-joint for AA6061 using Altair's HyperWeld and result obtained is with increase in tool rotational speed and pin diameter subsequently the temperature of weld bead increase.

The virtual experimental work is completed using Altair's HyperWeld friction stir welding. Altair's is a important computer-aided engineering (CAE) application. It can be used for linear as well as nonlinear structural analysis, structural optimization, computational fluid dynamics simulation, multiphysics simulation and also multibody dynamics applications. Altair has strong position in simulation technology that helps clients to analyze, simulate, visualize, and manage complex information [4]. Altair's HyperXtrude is an industry leading, general purpose, finite element based simulation software application within Altair's HyperWorks suite of CAE products. It provides a tightly integrated suite of best-in-class tools for all facts of the simulation process, including modeling, analysis, optimization, visualization, reporting, and collaborative knowledge management [5].

II. PROCESS METHODOLOGY

The friction stir welding simulation is done using Altair's HyperWeld CAE software. The literature available for study of the effect on peak temperature with the help of different geometric parameters as well as process parameters for different aluminum alloy material is very limited hence an effort has been made to understand effect of all this parameters on the material using HyperWorks. The workpiece materials are used as AA7075, AA6061, AA2219 aluminum alloy and tool material is H-13. Both aluminum alloy plates of size 381mm×127mm×6mm thick with the properties as shown in Table II are selected for the simulations & FSW tool of steel H-13 with the properties as shown in Table I are selected to perform virtual FSW process using Hyper Works 11.

TABLE I. H-13 TOOL MATERIAL PROPERTIES

Material (Steel Tool)	Density (Kg/m^3)	Specific Heat (J/Kg-K)	Conductivity (W/m-K)	Young Modulus (Pa)	Poisson Ratio
H-13	7870	460	24.3	2.1E+ 11	3.35

TABLE II. ALLUMINUM ALLOY MATERIAL PROPERTIES

Material (Al Alloy)	7075	6061	2219
Density (Kg/m^3)	2810	2700	2780
Specific Heat (J/Kg-K)	862	896	872
Conductivity (W/m-K)	134	180	193
Co-eff. Of Thermal Expansion (1/K)	1e.005	1e.005	1e.005
Liquidus Temp (K)	908.15	925	911
Solidus Temp (K)	748.15	855	775
Young Modulus (Pa)	7.2E+10	4.0E+10	4.0E+10
Poisson Ratio	3.3E-01	3.3E-01	3.3E-01

The process parameters used in simulations are three Shoulder Diameter (Sd) as (i) 12mm (ii) 18mm (iii) 24mm used. The welding speeds are selected as (i) 100mm/min (ii) 150mm/min (iii) 200mm/min and tool rotational speeds are selected as (i) 600rpm (ii) 1000rpm (iii) 1400rpm with initial temperature of plate is ambient temperature. The Tool geometry parameters are selected as shoulder length is 70.231mm, pin diameter (Pd) is 6mm, pin height is 5.2mm and tool tilt angle is 0°. Amongst this tool geometry parameters shoulder diameter are variable and shoulder length, pin diameter, pin length and pin tilt angle are kept constant throughout this simulation as shown in Fig.3.

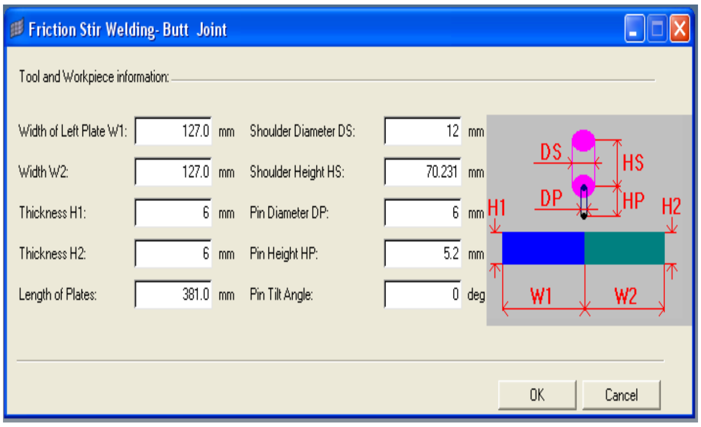

Fig. 3. Tool and Workpiece Information

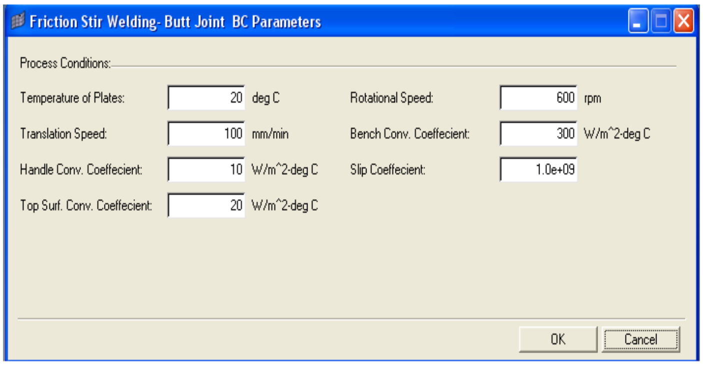

Fig. 4. Process Parameters Information

The virtual experiment performs on different combination of shoulder diameter and rotational speed and translational speed for each material as shown in Fig. 4. In each weld simulation, total iteration was kept constant at four so that results get with high accuracy.

III. RESULTS AND DISCUSSION

In this study, Understanding the heat generation and the temperature history during the FSW process is the first steps towards the understanding the thermo-mechanical interaction taking place during the welding process. The finite element weld simulation is performed to explore the effect of different tool rational speed, tool translational speed and tool shoulder diameter on peak temperature for welding of AA7075, AA6061 and AA2219 Al alloy plates. The heat transfer related boundary condition is applied on the entire surface of workpiece except the bottom of the plate is a convective heat transfer of 30 W/m²K whereas the natural convection is used between workpiece and air. A higher convective coefficient equivalent to conduction coefficient of 350 W/m²K is applied as a boundary condition to the bottom surface of the work piece. The results of the generated temperature profile are shown in the Fig. 5. It indicates the direction of heat flow in a material during process.

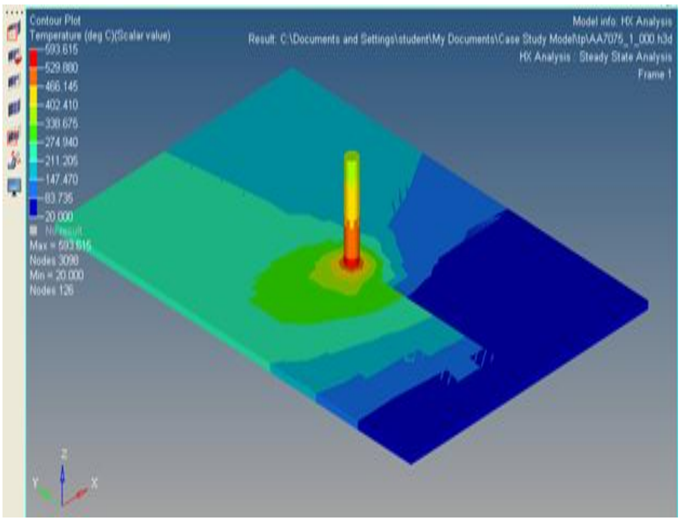

Fig. 5. Temperature Profile on Model

Heat Affected Zone (HAZ) in a material which highlighted by red colour as shown in fig.6 is indicate the peak temperature region generated during FSW process. At this region temperature as well as stresses are high than other part of workpiece. HAZ find at the contact between surface of tool pin, tool shoulder with workpiece. The different colour contour indicates the different temperature region or node at HAZ. Red zone indicate the highest temp region similarly blue region indicate that lowest temperature region (i.e. Reference Temperature) means in that region there is no transfer of heat from high temp node to low temp node.

The Fig.7. shows the different temperature zone during FSW process with the help of FE analysis with set parameters. It clearly indicates the different weld region in plate material and also show that the heat generated region at advance side (left Side) is more than retracting side. And it is found that the temperature at advanced side is larger than retract side because more plasticized mass deposited at advance side than retract side during the FSW process. The temperature at different position from center of the tool is also possible to predict.

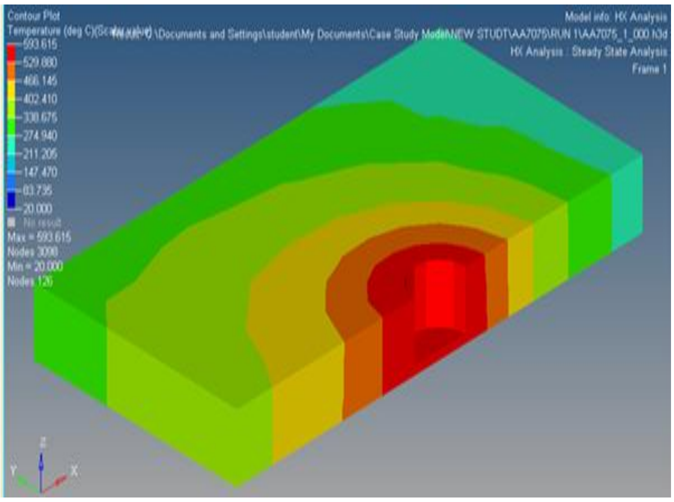

Fig. 6. Cross Sectional View of HAZ.

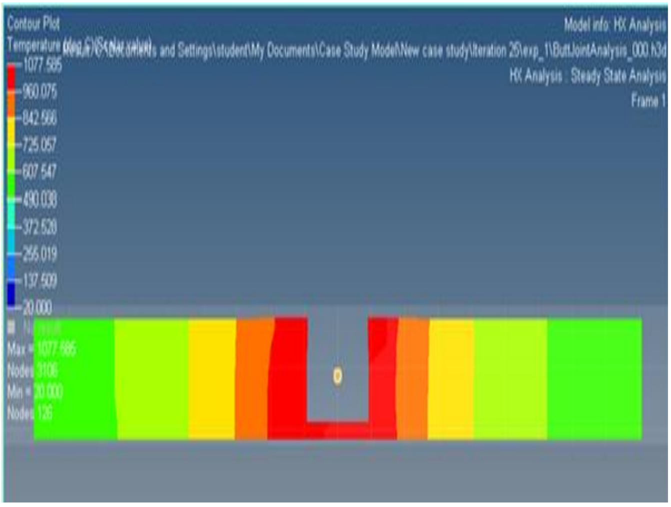

Fig. 7. X-Directional View of Temperature Profile

The tabulated results showing peak temperatures obtained by running the simulations up to four iteration on Hyper Works 11.0 to indicate the effects of varying welding parameters on aluminum alloy AA7075 and H-13 as shown in Table III. The different tool rotational speed (600, 100, 1400), tool translational speed(100, 150, 200), tool shoulder diameters(12, 18, 24) are considered for virtual experimental study and peak temperature at different combination of input parameters can be studied for heat generation

TABLE III. PEAK TEMPERATURE VALUES OF AA7075 & H-13

AA7075 And H-13				
RUN	*S_d (mm)*	*S_r (rpm)*	*S_t (mm/min)*	*Peak Temp (K)*
1	12	600	100	593.615
2	12	1000	150	827.368
3	12	1400	200	878.65
4	18	600	100	634.79
5	18	1000	150	815.03
6	18	1400	200	1008.79
7	24	600	100	677
8	24	1000	150	865
9	24	1400	200	1008.79

Above same procedure has been perform on remaining two material such as AA2219 and AA6061 with tool material remain same as H-13and process parameters are also same as above. The obtained peak temperature result of all materials which are used for simulation purpose has compare and the obtained results have mentioned in Table IV.

The peak temperature result of Table IV is studied with the help of graphical representation show in Fig.8. The Graphical representation i.e. Fig. 8 plot in-between the generated peak temperature at different workpiece material and Run which are taken during simulation. In first run the translational speed (S_t), shoulder diameter (S_d), rotational speed (S_r) are same for all material likewise its value different for the different run as per data shown in table 4.

TABLE IV. PEAK TEMPERATURE VALUES OF ALL MATERIALS

RUN	S_d (mm)	S_r (rpm)	S_t (mm/ min)	Peak Temperature (K)		
				AA7075	*AA6061*	*AA2219*
1	12	600	100	593.615	487.23	607.3
2	12	1000	150	827.368	524.74	755.57
3	12	1400	200	878.65	547.32	886.55
4	18	600	100	634.79	493.29	644.51
5	18	1000	150	815.03	515.83	827.47
6	18	1400	200	1008.79	546.38	986.31
7	24	600	100	677	519.17	683.62
8	24	1000	150	865	538.99	883.48
9	24	1400	200	1008.79	573.39	1046.37

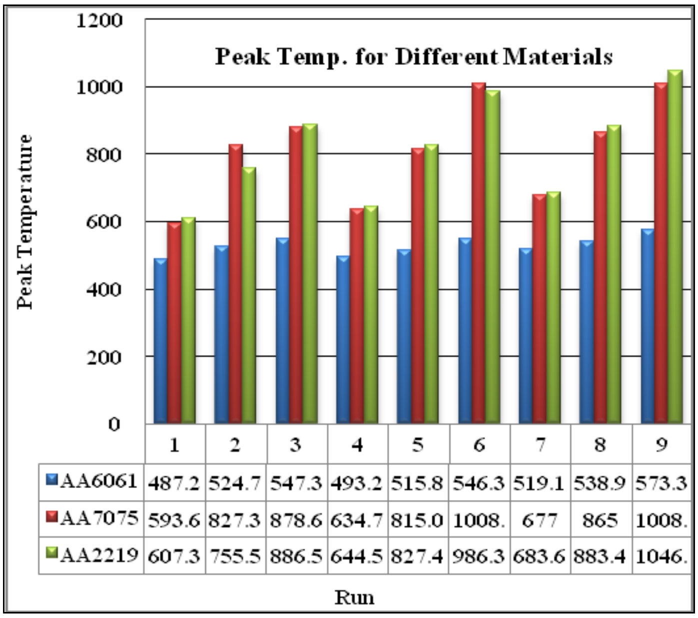

Fig. 8. Graph between Peak Temperature Vs Process Parameters

IV. CONCLUSION

FSW simulations performed on Altair's HyperWeld take towards the new opportunity of modeling and simulation of joining processes.

The following conclusions are predicted at the investigations made from the results of simulations for different tool parameters and base metal materials.

- Tool shoulder diameter is most responsible to produce heat at the tool and workpiece interface than the pin surface because with increase in shoulder diameter the temperature generated at contact surface also increased.
- As rotational speed increased the heat input per unit length of the joint increased.
- At the same translational speed (S_t), shoulder diameter (S_d) and rotational speed (S_r) the material AA6061 shows the lowest values of peak temperature than AA7075 and AA2219 aluminum alloy because the density of material is responsible for lowest peak temp i.e. density of welding material is directly affect on the heat generated during process.
- After comparing material properties of AA6061 With other two, it is also found that higher liquidus and solidus temperature give the lowest peak temperature.
- The temperature distributions also show that the temp at advance side is greater than the retracting side.

From the study of virtual experimental tabular data, concluded that it is necessary to produce minimum peak temperature for the production of better welded joint because material properties are changes at heat supplied. So future work is that to find the perfect combination set of input parameters which give lowest reading of peak temperature for any material so that materials properties can't change during process and get high strength weld. This works will helps in optimization of process parameters that can be carried out for the selected geometries of tool-pin parameters.

ACKNOWLEDGMENT

Authors would like to thank the G. S. Mandal's, Marathwada Institute of Technology, Aurangabad, to provide Center of Excellence–CAE and Research Centre to conduct experiment.

REFERENCES

[1] Gautam A. K., Kumar R., Kumar A., "Study of peak temperature in friction stir welded T-joint for AA6061 using Altair HyperWeld," International journal of Engineering Research and Technology(IJERT), Vol. 4, Issue 04, ISSN: 2278-0181, pp. 946-950, April 2015.

[2] Patel J. B., Patil H. S., "Simulation Of Peak Temperature & Flow Stress During FSW Of Aluminium Alloy AA6061 For Various Tool Pin Profiles," International Journal Of Materials Science And Engineering, vol. 2, no. 1, pp. 67-71, June 2014.

[3] Armansyah, Almanar I. P., Bahari Shaari M. S., Kasim A. A., "Temperature Distribution in Friction Stir Welding using Finite Element Metrhod," International journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering, vol. 8, no. 10, pp. 1662-1667, 2014.

[4] Mohd. Siddiqui A.,Jafri S. A. H, Alam S., "Thermal Study of simulated Temperature of Butt Joint during Friction Stir Welding of aluminum Alloy by using Hyperworks," International journal of Engineering Research and Application, vol. 5, Issue 1(Part 2), ISSN: 2248-9622, pp. 117-121, January 2015.

[5] Patil S., Lomte S., Dr. Gogte C. L., "Thermal Analysis of Friction Stir Welding joint of Age Hardenable AA 7075 using Altair's HyperWeld FSW," HTC-2012.

[6] Chen C. M., and Kovacevic R., "Finite Element Modeling Of Friction Stir Welding-Thermal And Thermomechanical Analysis," International Journal Of Machine Tools & Manufacture 43, pp. 1319–1326, 2003.

[7] Kiral B. G., Tabanoglu M.,and Serindag H. T., "Finite Element Modeling of Friction Stir Welding in Aluminum Alloys Joint, Mathematical And Computational Applications," vol. 18, no. 2, pp. 122 – 131, 2013.

[8] Grujicic M., He T., Arakere G., Yalavarthy H. V., Yen C. F., and Cheeseman B A., "Fully Coupled Thermomechanical Finite Element Analysis of Material Evolution During Friction Stir Welding of AA5083," Proc. ImechE Vol. 224 Part B, pp. 1-17, 2009.

[9] Weglowaski M. S., Hamilton C., Dymek S., "Numerical Modelling of Friction Stir Processing of AlSi9Mg Aluminium Casting Alloy," Biuletyn Instytutu Spawalnictwa. No. 6, pp. 12-22, 2013.

[10] Chodhuri B., Durgaprasad K., Debbarma S., Majumder A, and Saha S. C., "Parametric Optimization And Cost Estimation of AA6061 Weldments in Friction Stir Welding," International Journal of Mechanical And Production Engineering, Issn: 2320-2092, vol- 2, pp, 1-8, 2014.

[11] Dr. Jweeg M. J., Dr. Tolephih M. H., and Abdul-Sattar M., "Theoretical and Experimental Investigation of Transient Temperature Distribution In Friction Stir Welding of AA 7020-T53," Journal of Engineering. vol. 18, pp. 436-445, 2012.

[12] Kesharwani R. K., Panda S. K., and Pal S. K., "Multi Objective Optimization Of Friction Stir Welding Parameters For Joining of Two Dissimilar Thin Aluminum Sheets," Procedia Materials Science, vol. 6, pp.178 – 187, 2014.

[13] Hongjun Li and Di Liu, "Simplified Thermo-Mechanical Modeling of Friction Stir Welding with A Sequential FE Method," International Journal of Modeling and Optimization. vol. 4, No. 5, pp. 410-416, 2014.

[14] Khairuddin J. T., Abdullah J., Hussain Z., and Almanar I. P., "Principles and Thermo-Mechanical Model of Friction Stir Welding," InTech, pp. 191-216, 2012.