Analysis of Friction Stir Welding of Aluminum 7075-T4 Alloy Butt Joints

Suresh Arjula
Department of Mechanical Engineering,
JNTUH College of Engineering Jagtial-505501, Telangana, India
Email: arjulasuresh@jntuh.ac.in, arjula.sursh@gmail.com

ABSRACT

Friction stir welding is a solid state welding process which is finding increasing industrial acceptance for joining similar and dissimilar materials. In the present work, friction stir welding, a nonlinear thermal process is simulated using Altair's Hyper Extrude. The FSW of aluminum7075-T4 is analyzed for different process parameters like tool rotational speed and tool traverse speed. With the help of t different process and geometrical parameters the temperature, stress and strain distribution results are analyzed.

Keywords: *Al 7075-T4, Friction stir welding, Peak Temperature, Stress distribution.*

1. INTRODUCTION

Friction stir welding (FSW) is a material joining process with great potential as joint quality is exceptionally high and the process is very repeatable. Additionally, the process does not use fillers and, like fusion welding, eliminates the need for fasteners, which add weight to a structure. These attributes combined with its particular effectiveness on low-melting point alloys (which happen to be low-density) like aluminum and magnesium make FSW very applicable to vehicular applications where costs can easily be justified by increases in strength versus weight and high joint quality [1].
FSW is considered to be the most significant development in metal joining in a decade. Recently, friction stir processing (FSP) was developed for microstructural modification of metallic materials. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and subsequently traversed along the joint line (Fig. 1). The tool serves two primary functions: (a) heating of workpiece, and (b) movement of material to produce the joint. The heating is accomplished by friction between the tool and the workpiece and plastic deformation of workpiece. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. As a result of this process a joint is produced in 'solid state' [2]. Because of various geometrical features of the tool, the material movement around the pin can be quite complex. During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine and equiaxed recrystallized grains. The fine microstructure in friction stir welds produces good mechanical properties [2].

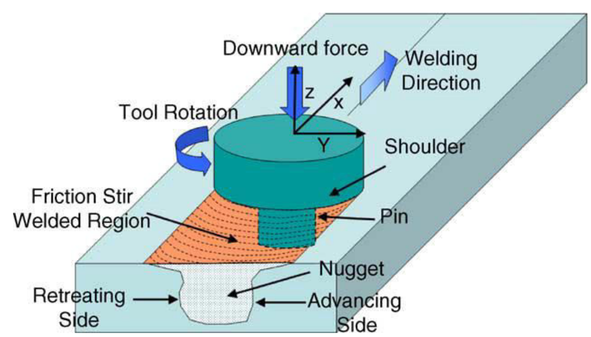
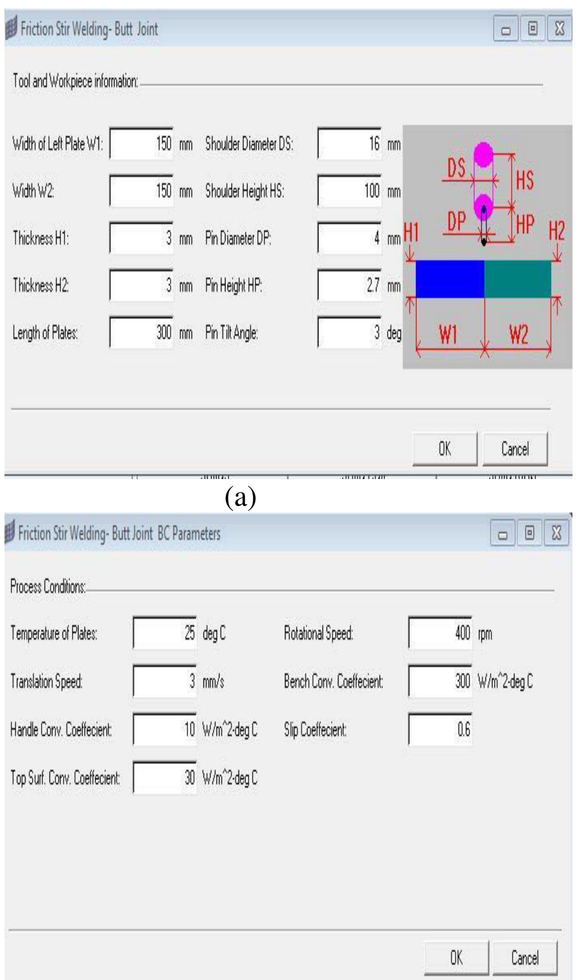


Figure 1. Schematic drawing of friction stir welding [2].

During FSW process it was observed that (1) the majority of the heat generated from the friction, i.e., about 95%, is transferred into the work piece and only 5% flows into the tool and (2) the fraction of the rate of plastic work dissipated as heat is about 80% [3]. Various investigators reported the effect of process parameters on thermal and mechanical properties of FSW of Aluminum alloys [4-9]. It was observed that the tensile strength initially increased with increase in tool rotational speed, welding speed and axial force but decreased after reaching a maximum value with further increase in these parameters [4]. Friction stir process produces very fine and homogenous grain structure and the smaller grain size structure is obtained at lower rotational speeds. The hardness of the processed sheet depends strongly on the rotational and translational speeds and varies widely within the processed region [5].

It was observed that the highest measured temperature is at the pin center. It can be noted that maximum workpiece temperatures have been reported at or near the joint line [10]. Various studies have been carried out to simulate thermal distribution in friction stir welding [11-15]. A moving heat source with a heat distribution simulating the heat generated from the friction between the tool shoulder and the work piece was used in the heat transfer analysis [11, 12]. It was observed that the maximum temperature near the weld increases as the tool holding time and rotational speed were increased. Temperature decreases as the tool transverse speed increases. In FSW, The peak temperature obtained was 70% of the melting point of parent metal [13]. The temperature distribution has been, with different tool geometry and process parameters, studied and reported that the material density and tool geometry has influence on heat generation in FSW process [14, 15].

2. MODELING



(a)

(b)

Figure 2. (a).Window shows the information about selection of Tool and work piece, (b) Window shows Friction stir welding-Butt joint Boundary conditions parameters.

In this present work the friction stir welding modeled with two 7075-T6 Al alloy plates, each with a dimension of 150 × 300 × 3 mm are butt welded in the adapted vertical milling machine for friction stir welding when HyperXtrude program is used. Fig. 2 shows the information about tool and work piece and boundary conditions of welded joint. The modeling of Friction Stir Welding carried out, shown in Fig. 3, using Altair Hyper works 12.0 HyperXtrude.

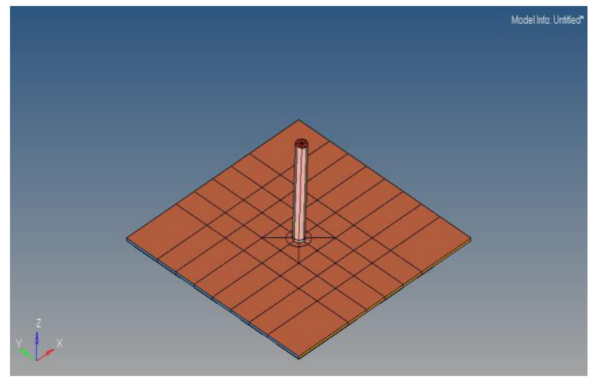


Figure 3. Friction Stir Weld model by HyperXtrude software.

In the present work, the shoulder diameter and tool diameter has taken as 16mm and 4 mm respectively. The Shoulder height and Pin height are taken as 100 mm and 2.7mm. Pin tilt angle taken as 3 deg [1].

Table 1. Material properties for workpiece and FSW tool.

Material Properties	**Al7075-T4**	**HS Steel Tool**
Density (kg/m^3)	2810	7870
Thermal Conductivity (W/m-°K)	173	24.3
Specific heat(J/kg-°K)	960	460
Young modulus(Pa)	4.00E+10	2.1E+11
Yield stress(MPa)	200-600	---
Co-efficient of thermal expansion(1/°K)	1.00E-005	---
Poisson Ratio	0.35	0.35
Volumetric Heat source(W/m^3)	12	700
Liquidus Temperature (°K)	908	---
Solidus Temperature (°K)	750	---

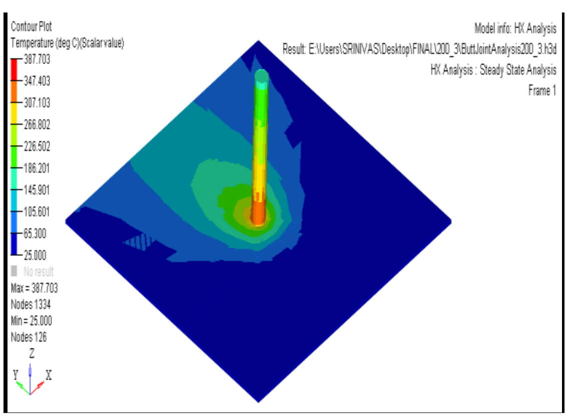
The material is assumed to be at an initial temperature of 25ºC which is similar to the ambient temperature and convective boundary conditions are applied to lines associated to the plate surface and tool surface. A convection coefficient (h) of 10 W/m^2 ºC is adopted for the Al7075 aluminum plate free surfaces. At the Al7075 aluminum plate bottom side or on workbench an equivalent convection coefficient (h) of 300 W/m^2 ºC is adopted to represent the heat transfer between the plate and the base. Finally, for the top of the tool an equivalent convection coefficient (h) of 300 W/m^2 ºC is adopted to represent the heat transfer between the tool and the mandrel [11]. Table 1 shows the material properties of friction stir welding tool and work piece.

In this work, the model is analyzed by varying the spindle speed as 200 rpm, 400rpm, 600 rpm, and 800 rpm and traverse speed taken as 1 mm/s, 2 mm/s, 3 mm/s, 4 mm/s, and 5 mm/s respectively. The Friction stir welding model has been analyzed in each of the varying parameter and each result were recorded and graphs were plotted for better knowledge.

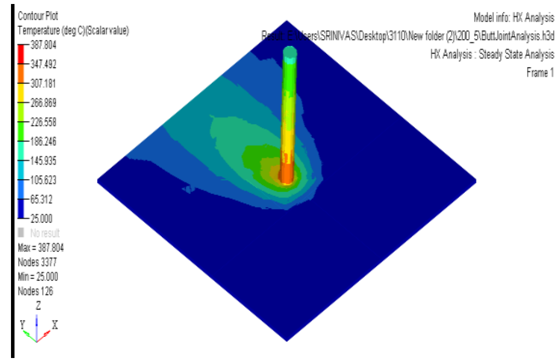
3. RESULTS AND DISCUSSIONS

3.1. Temperature Distribution

Temperature distribution is observed by plotting the graph with varying the tool rotational speed and transverse speed by keeping the transverse speed, spindle or tool rotational speed as constants respectively.

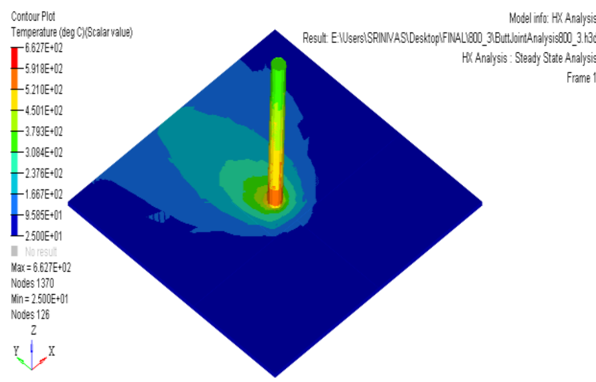


(a)

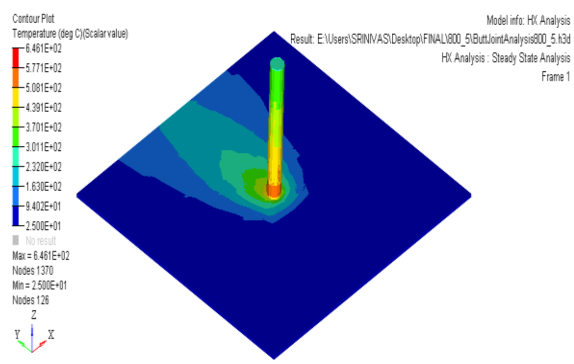


(b)

Figure 4.Temperature distribution contour plot for (a) rotational speed 200 rpm and transverse speed of (a) 3mm/s (b) 5 mm/s.



(a)



(b)

Figure 5. Temperature distribution for (a) rotational speed 800 rpm and transverse speed of (a) 3 mm/s (b) 5 mm/s.

Figure 4 and 5 show temperature contour plots for the tool rotational speeds of 200 rpm and 800 rpm respectively. The maximum temperature has been observed at underneath of the tool shoulder. The peak temperatures obtained at different rotational speeds as function of transverse speed are shown in Fig.6. The results show that the temperature increases with increase in rotational speed. It can be observed that the maximum temperature values decreases with increase in transverse speed and increases with increasing spindle speed (Fig. 7).

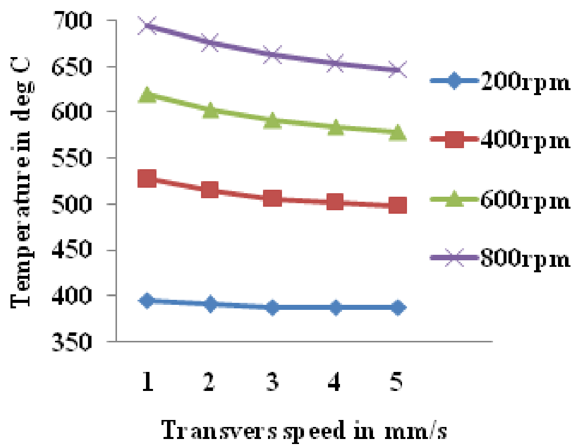


Figure 6. Peak temperatures values as function of transverse speed at different rotational speeds.

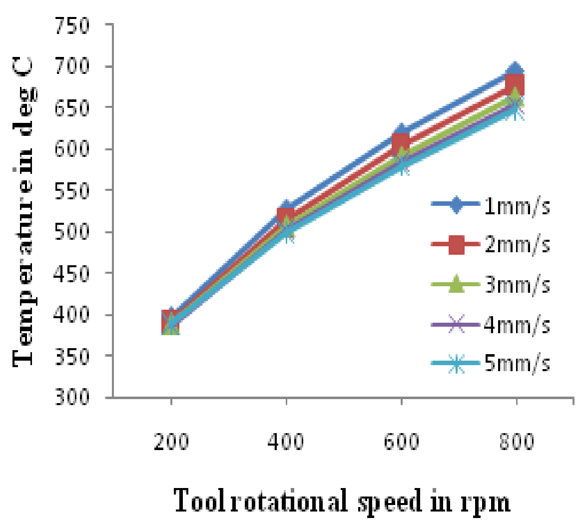
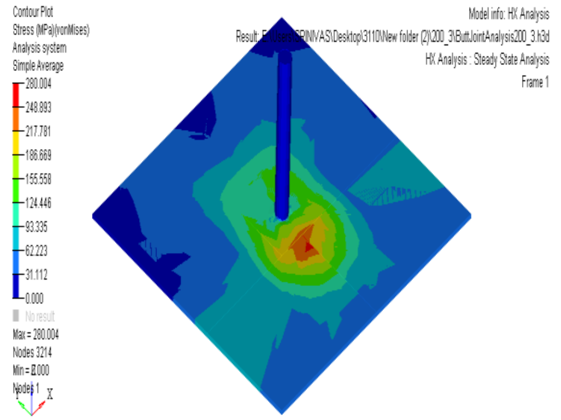


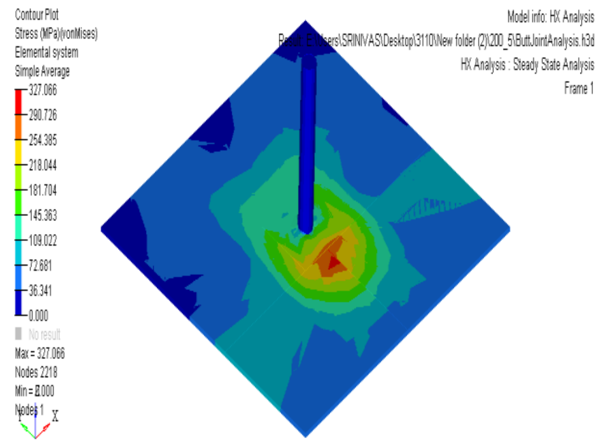
Figure 7. Variation of peak temperatures values as a function of rotational speed at different transverse speeds.

4.2. Stress Distribution

The maximum stresses can be observed by plotting the graph with varying the tool rotational speed and transverse speed by keeping the transverse speed, tool rotational speed as constants respectively.



(a)



(b)

Figure 8. Stress distribution contour plot for rotational speed 200 rpm and transverse speed of (a) 3 mm/s (b) 5 mm/s.

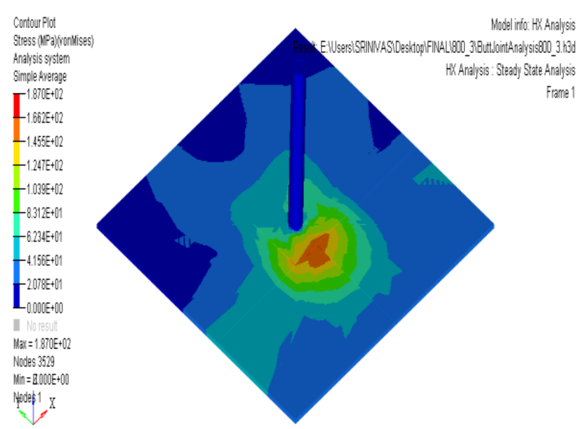
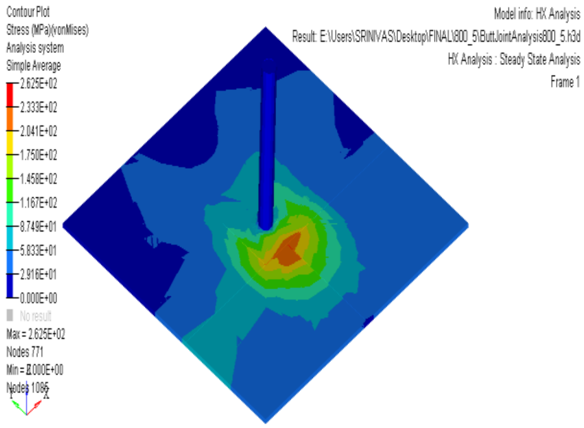


Figure 9.(a)Stress distribution contour plots for rotational speed 800 rpm and transverse speed of 3 mm/s.

(a)



(b)

Figure 9. Stress distribution contour plots for rotational speed 800 rpm and transverse speed of (a) 3 mm/s (b) 5 mm/s.

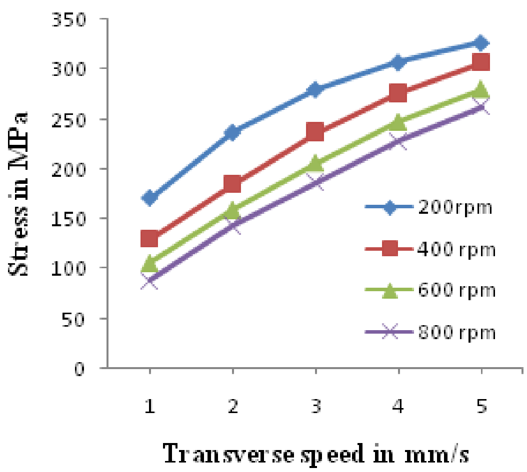


Figure 10. Maximum stress values as function of transverse speed at different rotational speeds.

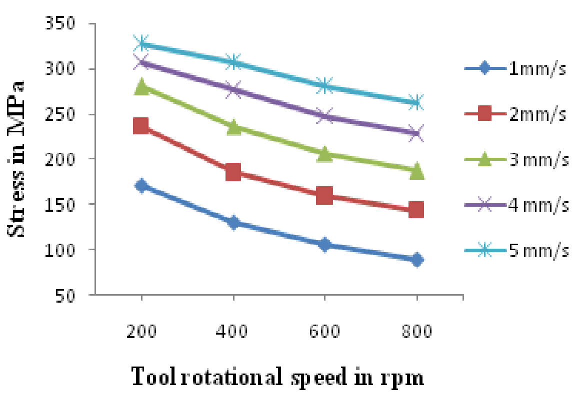
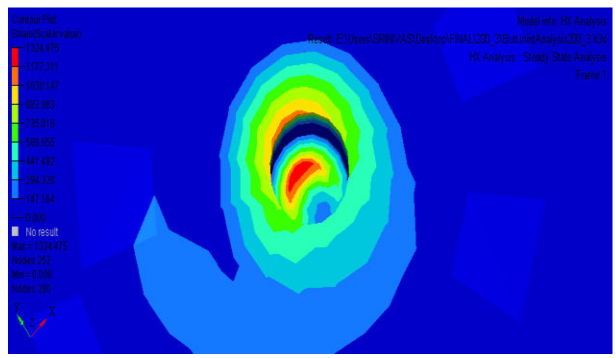


Figure 11.Maximum stress values as function of rotational speed at different transverse speed.

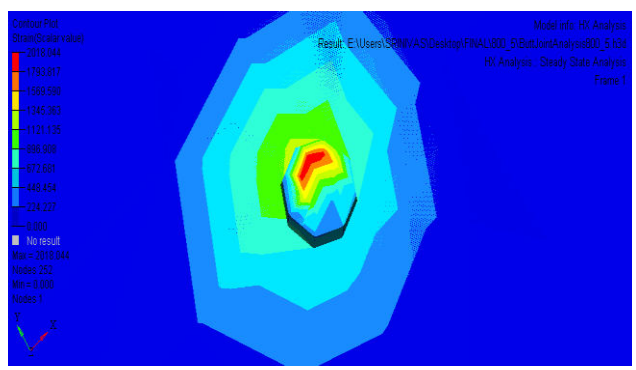
Fig.8 and Fig. 9 show contour plots of stress distribution and it is clear that the maximum stress values occur away from the tool. From Fig.10 and Fig.11, it can be observed that the maximum stress values increases with increase in transverse speed and decreases with increasing the rotational speed. The maximum stress value ranges from 150 to 350 MPa.

4.3. Strain and Strain Rate

The contour plot of strain and strain rate distribution of welded joint are shown in the Figure 12 and Fig. 13. Strain distributions are observed by plotting the graph with varying the tool rotational speed and transverse speed by keeping the transverse speed, tool rotational speed as constants respectively.

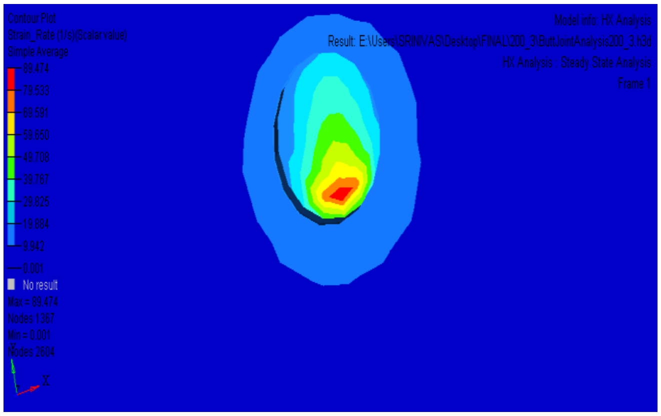


(a)

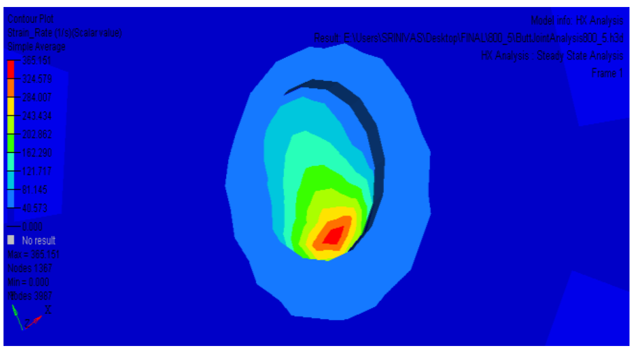


(b)

Figure 12. Strain distribution contour plot (a) rotational speed 200 rpm and transverse speed of 3 mm/s (b) for rotational speed 800 rpm and transverse speed of 5 mm/s.



(a)



(b)

Figure 13.Strain rate d contour plot for (a) rotational speed 200 rpm and transverse speed of 3 mm (b) rotational speed 800 rpm and transverse speed of 5 mm.

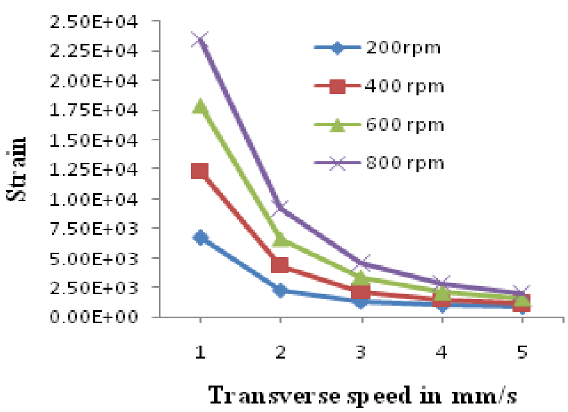


Figure 14. Maximum strain values as a function of transverse speed at different rotational speeds.

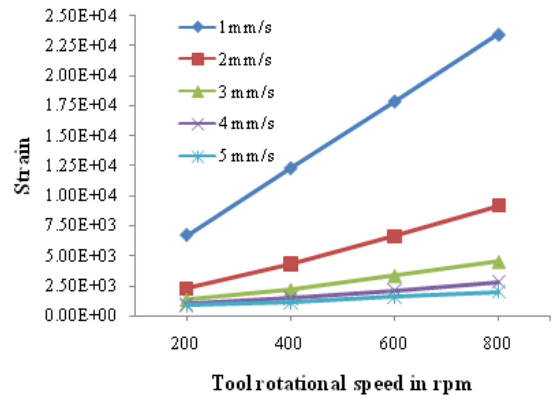


Figure 15. Maximum strain values as a function of rotational speeds at different transverse speed.

Figure 12and 13 shows that the maximum values of strain and strain rate occur below of the pin. Figure 14 and 15 show the variation of maximum strain values with rotational speeds and transverse speeds. It can be concluded that the maximum strain values are decreasing with increasing the transverse speed and increasing with increasing the tool rotational speed. Further. It is observed that that the maximum strain rate values are increasing with increasing the transverse speed. The tool rotational has prominent effect on strain and strain rate produced compared to transverse speed.

5. CONCLUSION

Based on the present work the following conclusions are made:

In this present work it may be concluded the maximum temperature is induced at the bottom of the tool pin in advancing side of the tool .The maximum temperature values are increases with increase in the rotational speed and the maximum temperature values are decreased with increased in the transverse speed. It is also observed that the variations in maximum temperature values with respect to transverse speed are very small as compared to the variation in the maximum temperature values with respect to rotational speed.

Based on the contour plots the maximum stress values are occur away from the tool. It is clear that maximum stress values are increases with increase in transverse speed and decreases with increasing the rotational speed. It is also observed that the variations in the stress values are accountable with respect to spindle speed and transverse speed.

Based on the contour plots of Strain and Strain rate it is observed that the strain and strain rate occur at the bottom of the tool pin. The maximum strain values are increased with increase in the spindle speed and decreased with increased in the increased in transverse speed. It is also observed that the variations in the strain values are accountable with respect to spindle speed and transverse speed. The maximum strain rate values are increased with increase in the spindle speed and transverse speed. It is also observed that the variations in the strain rate values with respect to spindle speed are more as compared to variations in strain rate with respect to transverse speed.

REFERENCES

1. Lammlein, D.H, Friction stir welding of spheres, cylinders, and t-joints: design, experiment, modeling, and analysis, Vanderbilt University, Nashville, Tennessee, 2010.

2. Mishra, R.S: Ma,.Z.Y; Friction stir welding and processing, *Materials Science and Engineering* R, 50, 2005, 1–78.

3. Yuh J. Chao, W. Tang- Heat Transfer in Friction Stir Welding-Experimental and Numerical Studies, Journal of Manufacturing Science and Engineering, 125, 2003, 138-146.

4. K. Elangovan, V. Balasubramanian and S. Babu, “Predicting tensile strength of friction stir welded 6061 aluminium alloy joints by mathematical model”, Material and Design, 30, 2009, 188-193.

5. Basil M. Darras- Experimental and Analytical Study of Friction Stir Processing, M.S. Thesis, University of Kentucky, 2005.

6. M Song and R Kovacevic- Numerical and experimental study of the heat transfer process in friction stir welding- Proc. Instn Mech. Engrs Vol. 217 Part B: J. Engineering manufacture, 2003, P73-86.

7. A. Scialpi, M. De Giorgi, L.A.C. De Filippis a, R. Nobile, F.W. Panella. Mechanical analysis of ultra-thin friction stir welding joined sheets with dissimilar and similar materials, Materials and Design, 29, 2008, 928–936.

8. G. Buffa, L. Fratini, S. Pasta- Residual stresses in friction stir welding: numerical simulation and experimental verification- JCPDS-International Centre for Diffraction Data, 2009.

9. Jyoti. K.Doley and Sachin D. Kore, A Study on Friction Stir Welding of Dissimilar Thin Sheets of Aluminum Alloys AA 5052–AA 6061, Journal of Manufacturing Science and Engineering, 138 (11) 2016, 502-507.

10. J. H. Record, J. L. Covington, T. W. Nelson, C. D. Sorensen, And B. W. Webb, **A** Look at the Statistical Identification of Critical Process Parameters in Friction Stir Welding, Welding Journal, April 2007, 97-103.

11.Binnur Gören Kıral, Mustafa Tabanoğlu, H. Tarık Serindağ, Finite Element Modeling of Friction Stir Welding In Aluminum Alloys Joint , Association for scientific research Mathematical and Computational Applications, Vol. 18, No. 2, 2013,.122-131.

12. Selvamani S.T 1, Umanath K 2 and Palanikumar K - Heat Transfer Analysis during Friction Stir Welding of Al6061-T6 Alloy, IJERA, 1,2008,1453-1460.

13. Muhsin Jaber Jweeg, Dr. Moneer Hameed Tolephih, Muhammed Abdul-Sattar Theoretical and Experimental Investigation of Transient Temperature Distribution in Friction Stir Welding of AA 7020-T53. Journal of Engineering volume 18 (2012).693-709.

14. K.D.Bhatt, Bindu Pillai, “Simulation of Peak Temperature & Flow Stresses during Friction Stir Welding of AA7050- T7451 Aluminum Alloy Using Hyperworks”, International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, Volume 2, Issue 5, 2012.

15. Satpute M.A.*et. al*., Thermomechanical Modeling of Friction Stir Welding for Different Material using Altair’s HyperWeld FSW, International Journal of Engineering Research & Technology, Vol. 4 Issue 12, 2015, 1-5.