

Thermal modelling of friction stir welding of magnesium alloy

Gurpreet Singh Phull^{a,*}, Piyush Gulati^b, Harpinder Singh^c

^aProfessor, School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab, India

^bAssistant Professor, School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab, India

^cAssistant Professor, School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab, India

*Corresponding author E-mail: gurpreet.s.phull@gmail.com

Abstract

The presented work was carried out to establish the correlation between the software simulation and real time experimentation for validation of temperature variation along the surface during friction stir welding of magnesium alloy. The alloy plates of AZ31 were used in the presented study. The simulation was conducted using Ansys software. The setup consist of TAAL Vertical machining center along with the thermocouples inserted in the predrilled holes in the plates for real time data collection. The temperature in the simulation at the interface of the tool and work piece reaches up to 600⁰C at various process parameters while in the setup the maximum temperature observed was of 409 ⁰C, the difference was owing to the location of the thermocouple.

Keywords: Friction stir welding, finite element analysis, Temperature profile, and Magnesium alloy

1. Introduction

The magnesium and its alloy has become the preferred material in the many industrial applications in general and automobile sector in particular, where the high weight to strength ratio is of importance. The magnesium alloy is 36% lighter than the aluminum and have good formability at elevated temperatures because of their hexagonal close packed structure [1]. The magnesium alloys are becoming an alternative for components of automobile and aerospace as

they are tougher than plastics, exhibit better damping performance in comparison to cast iron and aluminum, better heat dissipation and shields against electromagnetic interferences [2].

The traditional welding processes specially arc welding leads to heat affected zone, hot cracks, high residual stresses, porosity and degradation of the alloying elements due to evaporations. The process of solid state welding such as Friction Stir Welding (FSW) has shown an improvement in the weld ability of the magnesium alloy [3].

FSW developed in the 90s is a solid state welding process and have established as welding process for low melting point metals, such as aluminum. Though the FSW weld ability of magnesium alloy is quiet a matter of concern [1]. In FSW process a specially designed rotating tools create frictional forces at the interface of the two joining plates to heat the work piece as result of plastic deformation. The soften material of the plates by the spin of the tool fused with each other and resulted into a solid interface upon cooling. The process parameters those influence the FSW most are spindle speed, feed rate and depth of plunge, Shoulder temperature is most affectedby spindle speed, followed by pinlength, plunge depth, and feed rate [4]. The maximum temperature at the tool tip rather than the shoulder.

Temperature at different stages plays a crucial role in the successful bonding of the two plates. The temperature during the welding of 6061 T6 aluminum observed was not more than 0.8 Tm and maximum temperature zone was nearly constant through the center zone of the weld [5]. It was also observed that the temperature never reaches to the melting temperature of the material at the weld line. Number of researchers has established the FSW parameters for joining of aluminum and its alloys but for joining of magnesium still lot of research is required.

The thermal modelling of the FSW as suggested by various researchers helps to study the temperature distribution in the work piece. A systematic understanding based predictive model is of significant assistance for thoroughanalysis of FSW process [6].

It is observed that FEM model appropriately envisages the non-symmetricnature of FSW process, and the affiliations between the tool forces and the disparity in the process parameters. It

was observed that the FEM results were in sync with actual experimentation for the temperature distribution about the weld [6]. A good literature available for supporting the experimental analysis but very few publications report on the numerical modeling and simulation of the process due to the complex flow and difficulties in modeling the boundary conditions [7-8].

The foremost used methods are the Eulerian, the Lagrangian, the Arbitrary Lagrangian Eulerian (ALE), and more newly the Coupled Eulerian Lagrangian (CLE) technique. In the Eulerian method, the mesh is static and the material is able to transfer easily through it without element bend. The models based on the Eulerian approach [9, 10], are mainly used for estimating the material flow and temperature distribution during the FSW process. The Lagrangian technique is good for approximation of the temperatures and residual stresses. Though, severe mesh bends would happen since the mesh nodes will transfer together with the material in such a formulation. In the arbitrary Lagrangian Eulerian method [11-14] the mesh is not fixed in the space nor it is attached to the material. The mesh can transfer itself without the material thus allowing for acclimating re-meshing. Though, the ALE method does not model the diffusion of the tool into the surface of the plates to be welded. The coupled Eulerian Lagrangian formulation exhibits advantages of both the Eulerian and Lagrangian methods [15-16].

The data of Piyush et al. [17] for FSW of AZ31 magnesium alloy plates were used to validate the observations of the work presented in the paper.

2. MODEL DEVELOPMENT

The finite element technique used to solve is the continuum problems in which by dividing a complex structure into various continuous series of nodes that provides the nodal solution at each particular node and thus it is capable of solving the dynamic problems. This FEM analysis was performed using ANSYS software.

The thermal model has been used to study the transient temperature fields generated in the tool-work piece interface during the FSW process is provided by the three dimensional nonlinear heat transfer equation 1. Where, x, y, z are the spatial coordinates, T is transient temperature field a function of time (t), c is mass specific heat capacity. Q_{int} is internal heat source rate, ρ is density, and k is coefficient of thermal conductivity of the materials.

$$\kappa \left(\frac{\partial^2 T}{\partial x^2} \right) + \left(\frac{\partial^2 T}{\partial y^2} \right) + \left(\frac{\partial^2 T}{\partial z^2} \right) + Q_{int} = c\rho \frac{\partial T}{\partial t} \quad (1)$$

Material considered as homogenous and isotropic in the model, with the assumption that no melting takes place and heat losses are negligible. The material properties of the work piece are considered as mentioned in the work of piyush et al. [17] for Mg AZ31B, while the tool material is H13 steel.

Solid 70 brick element has been opted for modelling the 3-D thermal model of FSW in ANSYS. The figure 1 shows the 8 node element having the temperature at each nodes with single degree of freedom. Transient or steady state thermal analysis is relevant to three dimensional element that makes it possible to be opted as an appropriate model for FSW process.

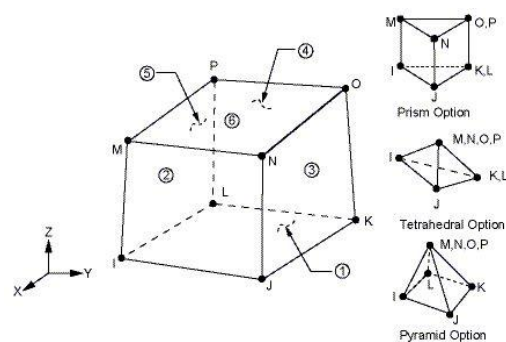
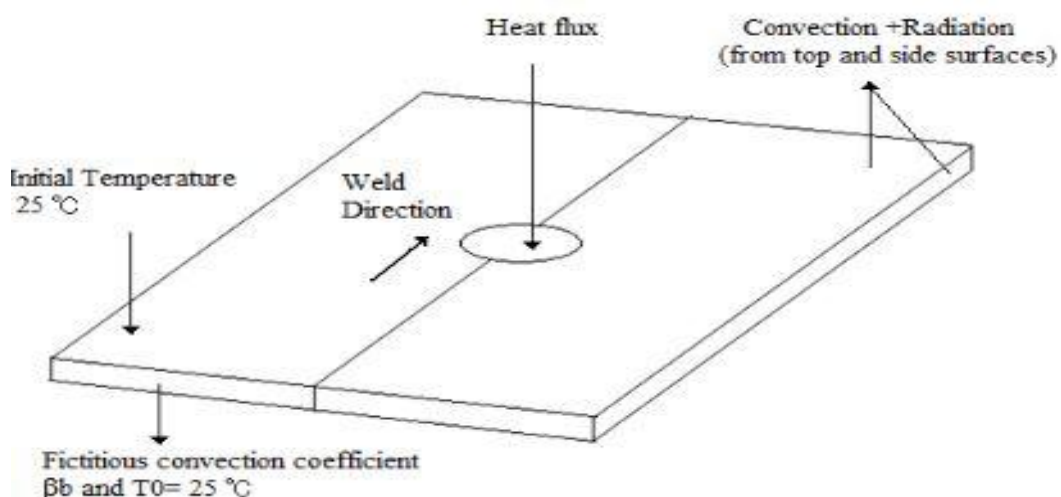


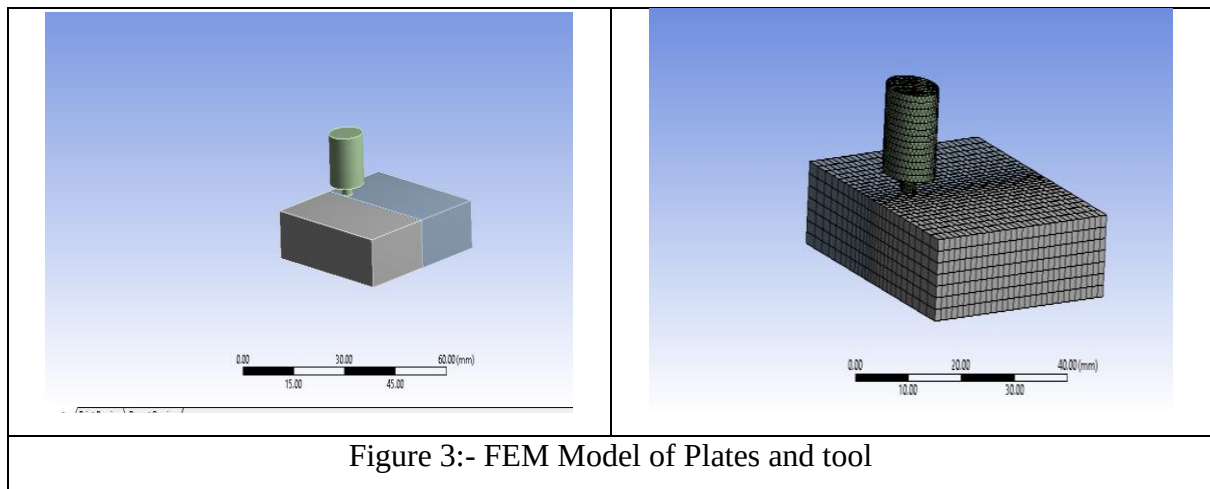
Figure 1 Three dimensional thermal solid element SOLID 70

The model is meshed with the help of three dimensional SOLID 70 elements. The model is meshed with volume mapped 4 to 6 sided. The mesh is comprised of a total 585 elements. The initial boundary conditions taken in Ansys the surface loads are specified for the FSW thermal



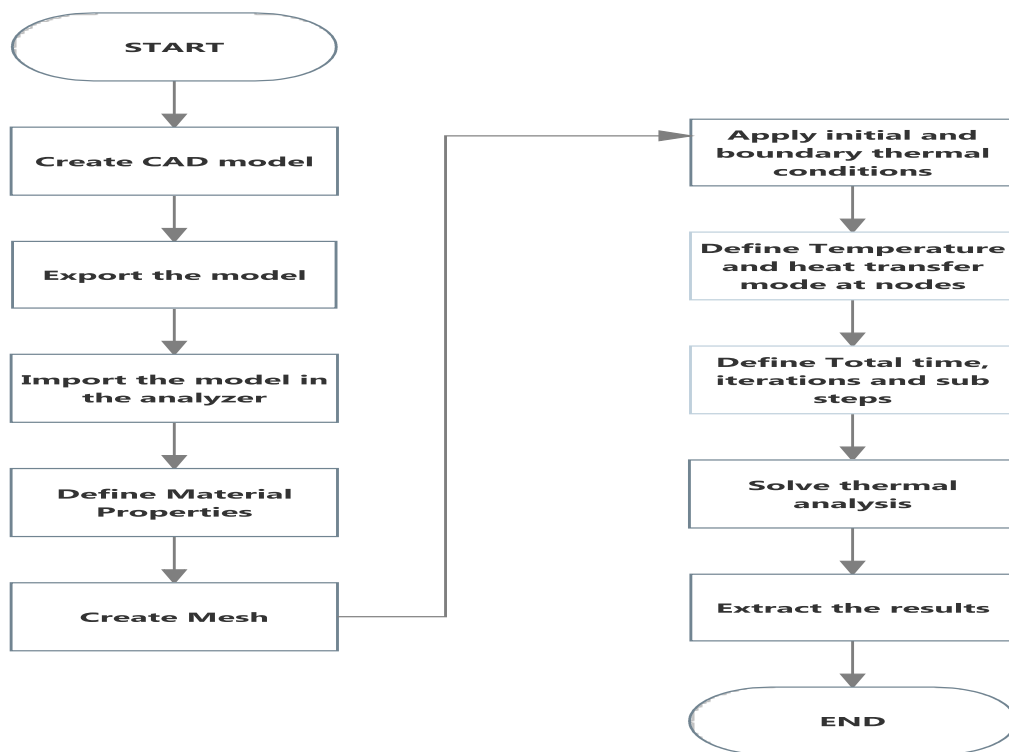
model as shown in the figure 2.

The modelling of friction stir arrangement of plates along with tool was done on CREO software and file is exported in IGES format to Ansys design modular for further analysis as shown in the figure3. Boundary conditions were specified using the Ansys on the mesh of the model along with the initial conditions.



The transient thermal analysis was performed using the software with full Newton_Raphson method for solving nonlinear equations. The finite element modelling for the thermal analysis is shown in the flow diagram in figure 4, full Newton-Raphson option have been utilized for solving the non-linear equation.

Figure 4 Flow chart for thermal analysis



3. Results

Figure 5 and Figure 6 shows the temperature distribution along the weld line of the process at start as the pin penetrates in the work piece and at the middle of the process where the sufficient heating

of the system has reached. It is evident from the figure 5 that with in no time the temperature reaches to 279.8 °C from a temperature of 21 °C at the start of the process. The temperature further rise to 610.8 °C as visible in the figure 6, in the vicinity of the tool and work piece, but the average temperature distribution in the heat effected zone is less than the melting temperature of the MgAZ31 B. The melting temperature of the Mg AZ31 B hot rolled plate material reported in the literature is around 605 – 630°C. Which confirms that the joining of the material is done below the melting temperature of the material by the material deformation because of frictional heat.

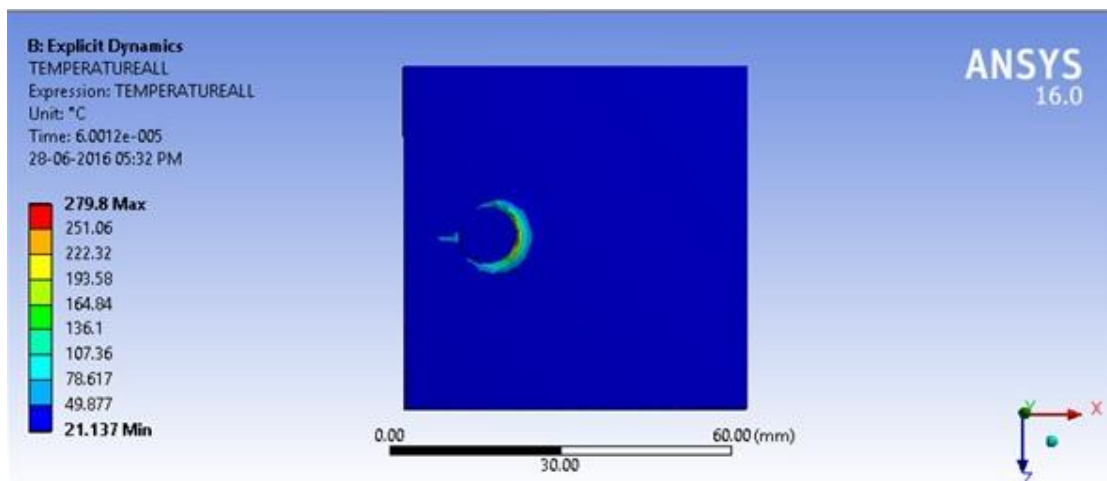


Figure 5 Temperature distribution at the start of the process

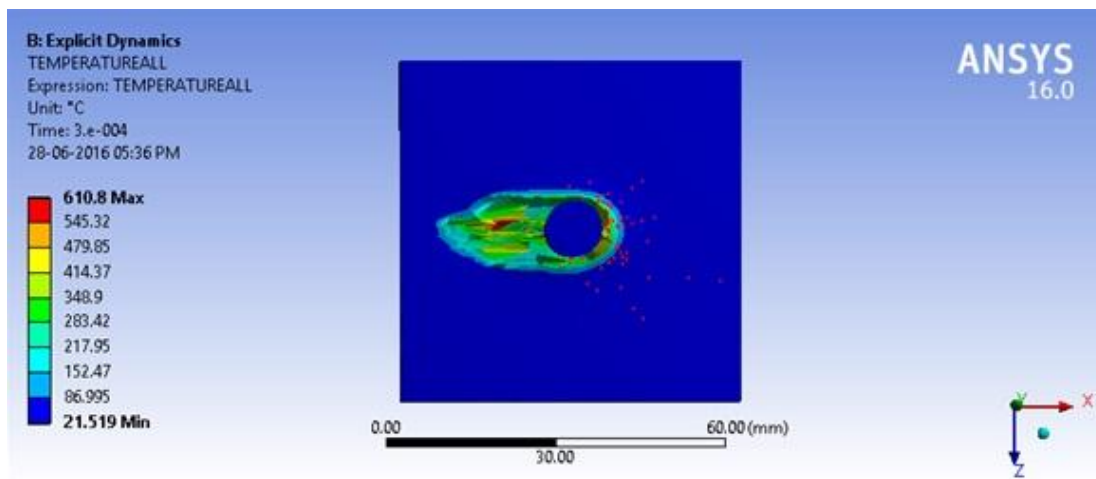


Figure 6 Temperature at the middle of the process

Friction stir welded AZ31B magnesium alloy plates of 6 mm thickness were prepared using vertical milling CNC. The detail of the process parameters and setup configuration can be read in

the work of piyush et al [17]. Thermocouples as shown in Figure 7 were installed at different location to measure the temperature at different process parameters.

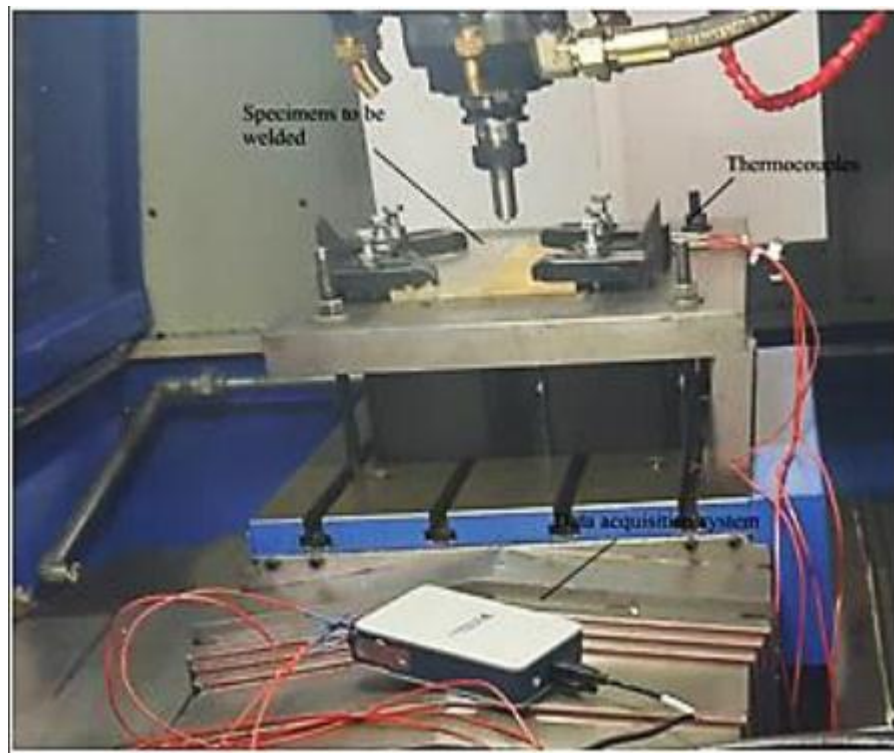


Figure 7 Setup for Friction Stir Welding of Mg AZ31B

The observations taken in the experiment are reproduced in the table 1.

Parameters		Thermo Couple 1 ($^{\circ}\text{C}$)	Thermo Couple 2 ($^{\circ}\text{C}$)	Thermo Couple 3 ($^{\circ}\text{C}$)	Thermo Couple 4 ($^{\circ}\text{C}$)
Rotation Speed (RPM)	Welding Speed (mm/min)				
1200	80	242	251	278	321
	100	253	263	280	333
	120	265	272	286	323
1500	80	269	285	305	366
	100	285	292	302	363
	120	272	276	301	346
1800	80	289	305	357	404
	100	291	321	380	409
	120	290	319	345	394

The Temperature measured through the thermocouples was form 240°C to 409°C in the vicinity of the tool and work piece interface, which appear to be in sync with the temperature variation

shown in the figure 6. Although the maximum temperature indicated in the FEM analysis is 610 °C in the weld line, but it can be safely commented that the actual temperature would also be nearing the same value, by interpreting data in the table 1. It is due to the fact that thermocouples were placed at a certain distance from the weld line owing to the safety of the thermocouples hence the temperature at the interface cannot be measured directly with this setup. So it can be concluded that the temperature at the location of the thermocouple is less due to the heat transfer in the plates and in to the atmosphere.

4 CONCLUSIONS

In this study the experimental observation were found to be in sync with the simulation results.

The following conclusions are drawn:

- The temperature distribution along the weld line was in the range of 150 °C – 610.8 °C which is close to the melting temperature of the material.
- The experimental data shows a variation in temperature of 242 °C – 409°C at different locations for different process parameter.
- The FEM Simulation if designed with proper boundary conditions can yield results nearing to the actual setup.

References

1. Commin L, Dumont M, Masse JE, *et al.* Friction Stir Welding of AZ31 Magnesium Alloy Rolled Sheets: Influence of Processing Parameters. *Acta Mater.* 2009; 57(2): 326–4p.
2. B. L. Mordike, T. Ebert, “Magnesium – applications – potential”, *Journal of Material Science Engineering A* 302, pp. 37-45, 2001
3. Pareek M, Polar A, Rumiche F, *et al.* Metallurgical Evaluation of AZ31B-H24 Magnesium Alloy Friction Stir Welds. *J Mater Eng Perform.* 2007; 16(5): 655–4p.
4. 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, pp. 97-103

5. Tang W, Guo X, McClure JC, Murr LE., Heat Input and Temperature distribution in Friction Stir Welding. *Journal of Material Processing and Manufacturing Science*. 1998;7: pp 663-672.
6. G. Buffa G. Buffa, J.Hua, R. Shivpuri, L. Fratini,” A continuum based fem model for friction sti welding—model development”, *Materials Science and Engineering* 2006, A419,pp 389-396
7. Tanmoy Medhi, BarnikSaha Roy, SubodhDebbarma, S.C.Saha, “Thermal modelling and effect of process parameters in friction stir welding”,*Materials Today: Proceedings*, 2015; 2(15): pp3178-3187.
8. P. Prasanna&B. Subba Rao&G. Krishna Mohana Rao,”Finite element modeling for maximum temperaturein friction stir welding and its validation.” *Int J Adv Manuf Technol* (2010) 51:925–933
9. P.Ulysse, Three-dimensional modeling of the friction stir-welding process, *Int. J. Mach. Tool. Manu.*42(2002) 1549–1557.
10. P.Colegrove, R.Shercliff Hugh, 3-Dimensional CFD modeling of flow round a threaded friction stir welding tool profile, *J. Mater. Process. Technol.*169 (2005)320–327.
11. X.Deng, S.Xu, Two-dimensionalfinite element simulation of material flow in the friction stir welding process, *J. Manuf. Process.* 6(2) (2004)125–133.
12. H.W.Zhang, Z.Zhang, J.T.Chen, 3D modeling of material flow in friction stir welding under different process parameters, *J. Mater. Process. Technol.*183 (2007)62–70.
13. H.Schmidt, J.Hattel,A local model for the thermomechanical conditions in friction stir welding, *Modell. Simul. Mater. Sci. Eng.*13(2005)77–93.
14. Z.Zhang, H.W.Zhang, Numerical studies on controlling of process parameters in friction stir welding, *J. Mater. Process. Technol.*209(2009)241–270.
15. E.M. Kishta, F.H. Abed, B.M. Darras, Nonlinear Finite Element Simulation of Friction StirProcessing of Marine Grade 5083 Aluminum Alloy, *Engng. Trans.* 62(4) 313-328.
16. S. Kouadri, K. Necib, S. Atlati, B. Haddag,M. Nouari, Quantification of the chip segmentation in metal machining: Application to machining the aeronautical aluminium alloy AA2024-T351 with cemented carbide tools WC-Co, *Int. J. Mach. Tool. Manu.*64 (2013) 102-113.
17. Piyush Gulati, Dinesh Kumar Shukla, Gurpreet Singh Phull,Influence of Process Parameters on Temperature Distribution and Microstructure of Friction Stir Welded Magnesium Alloy, *Journal of Thermal Engineering and Applications*, 3(3), 27-33.