Analysis of friction stir Welding of dissimilar Aluminium alloys

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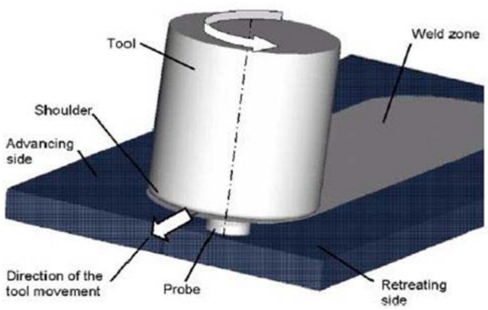
***Abstract*— Friction Stir Welding (FSW) has a potential for wide-spread applications. Aluminum alloys generally have low weld ability with traditional fusion-welding process. However, the development of Friction Stir Welding (FSW) has provided an alternative, improved way of producing aluminum joints, in a faster and more reliable manner. The FSW process has several advantages, in particular the possibility to weld dissimilar aluminum alloys. However it is necessary to overcome some challenges for its wide-spread uses. Tool design and the selection of process parameters are critical issues in the usage of this process. This study focuses on the process parameters that is required for producing effective friction stir welding of two dissimilar alloys AL6101-T6 alloy to AL6351-T6 alloy. Simulation offers some potential advantage especially when temperature profile is to find out to study the HAZ over weld region. In this present work, thermal numerical simulation is being conducted using software tool ANSYS. In this work the maximum peak temperature being calculated and plotted against the different varied parameters i.e. rotational speed of tool.**

Keywords-Friction Stir Welding,Tool design; dissimilar alloys ;. Simulation , ANSYS.

I. INTRODUCTION

Friction stir welding (FSW) is a recently emerged solid-state joining technology patented by The Welding Institute (TWI) in 1991[1]. Welding is defined by the American Welding Society (AWS) as a localized coalescence of metals or non-metals produced by either heating of the materials to a suitable temperature with or without the application of pressure, or by the application of pressure alone, with or without the use of filler metal. Welding techniques are one of the most important and most often used methods for joining pieces in industry. Any information about the shape, size and residual stress of a welded piece is of particular interest to improve quality. FSW is based on strong couplings of thermo-mechanical phenomena. It induces very complex material motions and large shear forces. The material temperature is raised to about 80% of the melting temperature .Never the less the simulation of the process will be a further aim, as it is difficult to be numerically modeled due to the complex thermal and material flux occurring during the process, similar to Friction Stir Welding. The conventional processes, working with molten phases are characterized by large heat input, which can change the microstructure of the diverse materials. This can provide mixed phases, which are very brittle and hardly formable, as well as hot cracks due to shrinkage during cooling or shape deviation. Contrary to melting joining techniques Friction Stir Welding is characterized as a solid phase welding technology, which was patented in 1991[2]. The probe primary function is to mix the material under the tool shoulder, which can be enhanced by threads. FSW is actually performed in three steps. First, the probe is plunged into the joint formed by the two sheets to be welded, until the shoulder gets in contact. As the tool rotates at a high velocity, the sheets are heated up by plastic deformation and friction. Second, the tool keeps rotating without any translational motion, so the material heating due to friction increases. Finally, the tool moves along the joint line, heats the material further, moves it from the front of the tool, and deposits it behind its trailing edge, producing the weld. This process is illustrated in Fig. 1[3].



. Fig. 1.A schematic illustration of FSW process

II. SCOPE AND OBJECTIVES

In any structural application Aluminum occupies an important position in the family of metals Its lightweight, high strength and corrosion resistance are utilized extensively by modern designers to conserve energy and materials. Friction stir welding (FSW) process is a new technique and finds wide application . From the literature review, it is understood that lot of research work has been carried out to understand the effect of tool profiles on friction stir welding process. The purpose of this experiment is to identify the effect of tool rotational speed and to study the temperature profile generated during FSW to identify the temperature at various weld zones.

A. SELECTION OF WORKING MATERIAL

1) The First Work piece is of Grade Al 6101 T6 and its composition given below. Work piece is having cross-section of 150X50X12 mm. T6:- Solution heat-treated and then artificially aged.

Table-1

Constituents	Cu	Mg	Si	Fe	Mn	Al
%	0.05	0.65	0.5	0.5	0.03	rest

2) second work-piece was of Grade Al 6351 T6 and its composition given below.

Table-2

Constituents	Cu	Mg	Si	Fe	Mn	Al
%	0.10	0.80	0.95	0.60	0.70	rest

Second Work piece was having cross-section of 150mmX50 mmX12mm. The dimension of the both work piece has been kept 150 mm × 50 mm ×12 mm for each of the Al-alloy for making FSW butt joint as shown in Fig.

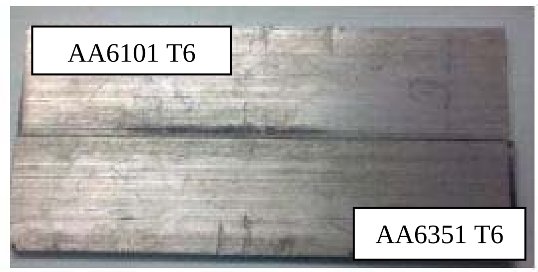


Fig. 2. working AL-plates to be welded

Table 3: Mechanical properties of working materials.

Properties	Aluminum 6101T6	Aluminum 6351T6
Density	2.70 g/cc	2.71 g/cc
Tensile Strength, yield	193 MPa	283 MPa
Modulus of Elasticity	68.9 GPa	68.9 GPa
Poissons Ratio	0.33	0.33
Shear Modulus	26.0 GPa	26.0 GPa
Specific Heat Capacity	0.895 J/g°C	0.890 J/g°C
Thermal Conductivity	218 W/mK	176 W/mK
Solidus	621 °C	554 °C
Liquidus	654 °C	649 °C

The above properties were supplied as inputs in engineering data section in ANSYS.

B. SELECTION OF FSW TOOl.

Friction stir welding tool has been fabricated with high carbon and high chromium tool steel. (the composition shown below)

Table no.4

Constituents	C	Si	Mn	P	S	Cr	Fe
Wt %	1.82	0.479	0.61	0.028	0.036	11.93	Bal

The fabricated tool tip was tapered and cylindrical threaded having shoulder diameter 25mm and pin base diameter 8mm and pin tip diameter 6mm.The tool tip length was 11.6 mm which was less than that of thickness of the material.

Fig. 3. Fabricated FSW Tool with threaded tip

Table 5: Mechanical properties of FSW Tool material

Properties	Value
Density	7700 kg/m3
Modulus of Elasticity	210 Gpa
Hardness, Brinell	255
Ultimate tensile strength	1736 Mpa
0.2% offset yield strength	1532 Mpa
Poisson's ratio	0.27-0.3

C. WELDING PROCEDURE.

Friction stir welding set up has been made on a milling machine having capacity 7.5 HP . In this process FSW tool was attached to the tool post and rotated tool has been plunged into the joint line between two pieces of working plate material (AL6101 T6and AL6351 T6), which were butted together as shown in Fig. 4 .The working plates have been clamped rigidly clamped onto a backing plate in a manner that prevents the abutting joint faces from being forced apart. The length of tool pin was slightly less than the weld depth required and the tool shoulder had been in intimate contact with the work piece surface during welding process. Frictional heat is generated between the wear resistant welding tool shoulder and pin, and the material of the work-pieces. This heat, along with the heat generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without reaching the melting point (hence cited a solid-state process). As the pin is moved in the direction of welding the leading face of the pin assisted by a special pin profile, forces plasticized material to the back of the pin while applying substantial pressure force to consolidate the weld metal[4]. The Temperature values in the test are measured at the mid-plane of the plates with thermocouples inserted in small holes drilled in the plates as shown in Fig.3. The holes are aligned along a line normal to the welding direction. Temperature history values at various distances away from the weld line are then measured. Based on the measured values and steady-state condition, temperature variations along lines passing the measurement points and parallel to the weld line can be derived . The process parameters such as tool shoulder diameter, tool rotational speed & feed rate were considered by keeping the axial force constant.

Fig. 4. FSW experimental Set-up

D. EXPERIMENTAL PROCESS PARAMETERS.

Table -6 In put process parameters for welding.

Joint No.	**Rotation speed(RPM)**	**Feed (mm/min.)**	**Shoulder dia (mm)**	**Pin dia (mm)**
1	900	16	25	8
2	1000	16	25	8
3	1100	16	25	8
4	1200	16	25	8

Data of each experiment was colleted at 5mm interval starting from edge of AA 6351T6 and moving towards other plate end. Temperature at each region was noted down and with that graph was plotted.

E. FLOW CHART OF EXPERIMENT.

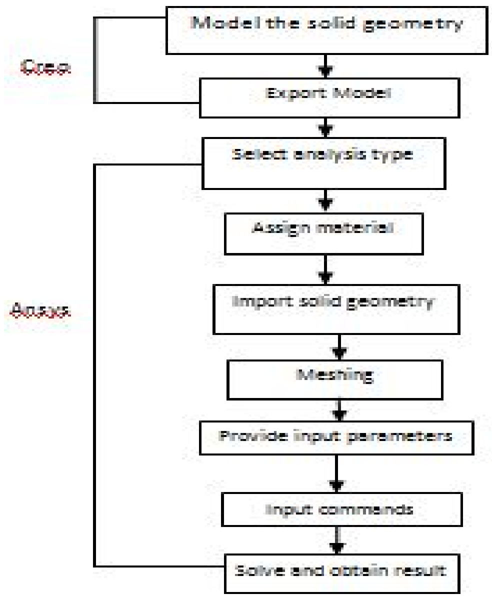


Fig-5 Flow chart of the experiment

F. MODELING & SIMULATION

Solid modeling or modeling is a consistent set of principles for mathematical and computer modeling of three-dimensional solids. Together, the principles of geometric and solid modeling form the foundation of computer aided design and in general support the creation, exchange, visualization, animation, interrogation, and annotation of digital models of physical objects. Modeling is done using Creo 2.0. The parts created are assembled using assembly option . As the default saving format in this software is ".prt" for part file and for assembled part is ".asm" hence it must be converted to other format . Various other 3d formats are supported. Here we have chosen ".igs" format for exporting. A computer simulation is a simulation, run on a single computer, or a network of computers, to reproduce behavior of a system. The simulation uses an abstract model (a computer model, or a computational model) to simulate the system. A computer model is the algorithms and equations used to capture the behavior of the system being modeled. By contrast, a computer simulation is the actual running of the program that contains these equations or algorithms. Simulation, therefore, is the process of running a model. Here simulation is done in ANSYS 14 in workbench interface which uses FEM to solve the model. For this simulation "transient structural analysis" is selected. As this analysis by default does not gives output values in temperature. Certain commands are placed at various locations to activate frictional and thermal properties of material, this is also called user defined functions(UDF).

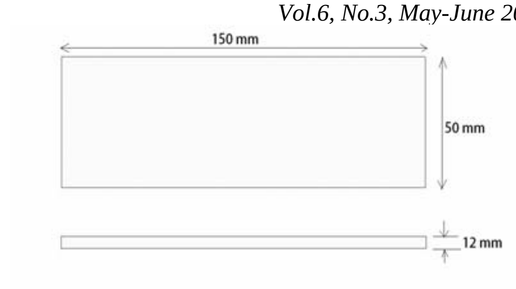


Fig-6 schematic diagram of work piece.

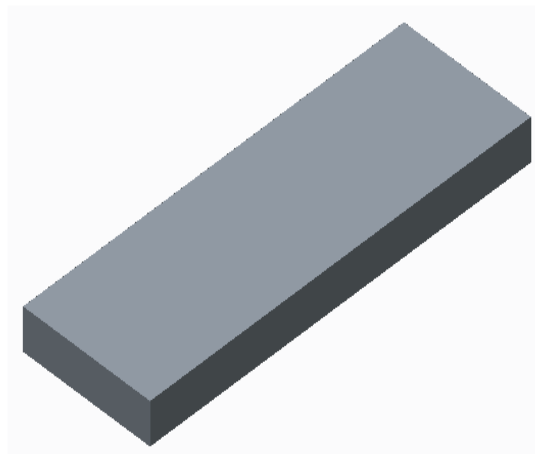


Fig-7 Model of work piece.

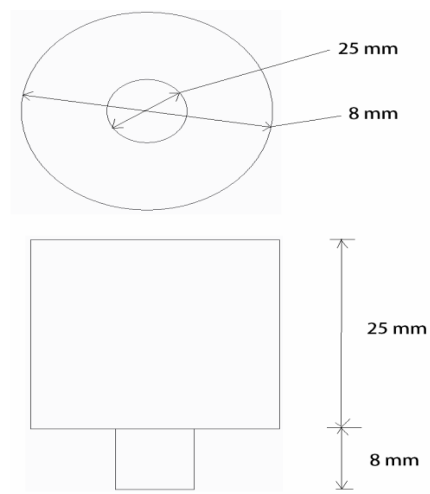


Fig-8 Schematic diagram of tool.

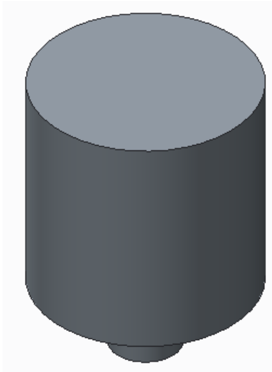


Fig-9 Model FSW Tool

G. *MESHING.*

Mesh generation is the practice of generating a polygonal or polyhedral mesh that approximates a geometric domain. The term "grid generation" is often used interchangeably. Typical uses are for rendering to a computer screen or for physical simulation such as finite element analysis or computational fluid dynamics. Three-dimensional meshes created for finite element analysis need to consist of tetrahedral , pyramids, prisms or hexahedra. Those used for the finite volume method can consist of arbitrary polyhedral . Those used for finite difference methods usually need to consist of piecewise structured arrays of hexahedra known as multi-block structured meshes. A mesh size of 5mm was chosen. This was done as a smaller mesh was taking huge amount of time for solving. The plate was brick meshed while the tool was meshed by triangle and brick mesh.

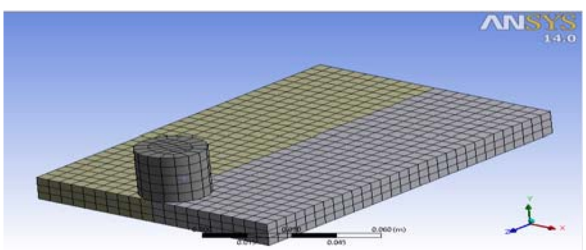
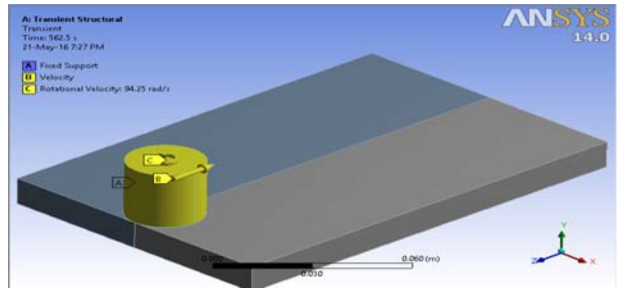


Fig-10 Modeling & meshing of joint.

H. *INPUT PARAMETERS.*

Fixed support is provide at the bottom of both plates
Time =distance/speed=150/16= 9.375min= 562.5 sec.
Velocity =16mm/min = 16/(1000x60) = 2.67×10^{-4}m/sec.
Load = 8kg=8x9.81 N=78.48 N

Rotational velocity
900rpm = (900x2xpi)/60 = 94.25 rad/sec.
1000rpm=(1000x2xpi)/60 = 104.71 rad/sec.
1100 rpm = (1100x2xpi)/60 = 115.19 rad/sec.
1200 rpm = (1200x2xpi)/60 = 125.66 rad/sec
Frictional coefficient- Static= 0.61, Sliding=0.47



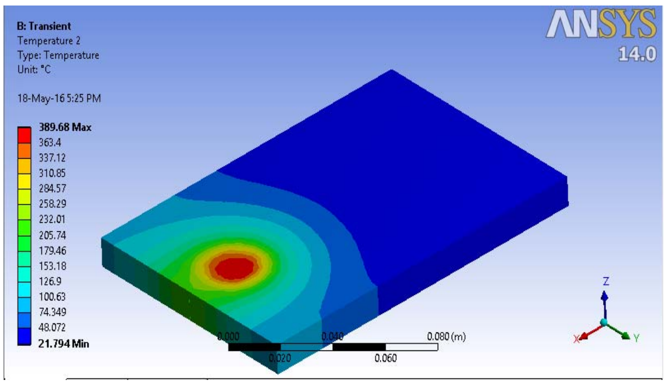
Setup at 900rpm

I. *INPUT COMMANDS.*

Table-7

Command	Use	Location used
et, matid,226,11	For assigning element number 226 to the part and enabling extra DOF for the part by 11	All solid models created
keyopt,cid,1,1	This enables temperature as DOF for structural analysis.	Used at the contact plane between tool and the workpiece
remodif,cid,15, 1	This defines the value of 15th real constant which is "FHTG". It specifies the fraction of frictional dissipated energy converted to heat.	
remodif,cid,18,0.5	This defines the value of 18th real constant "FWGT". It specifies the weight factor for the distribution of heat between the contact and the target surfaces for thermal contact.	
tref,22	Defining reference temperature.	
cmsel,s,temp	Select nodes on face.	
d,all,temp,22	Assign initial value to the nodes.	
allsel,all	Select all the entites on the face while solving	Placed at location of analysis type

III. RESULT AND DISCUSSIONS.



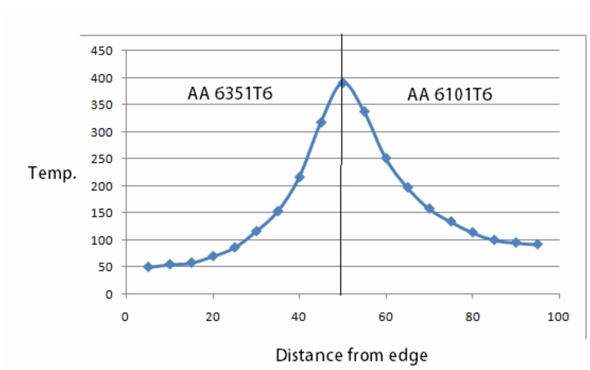
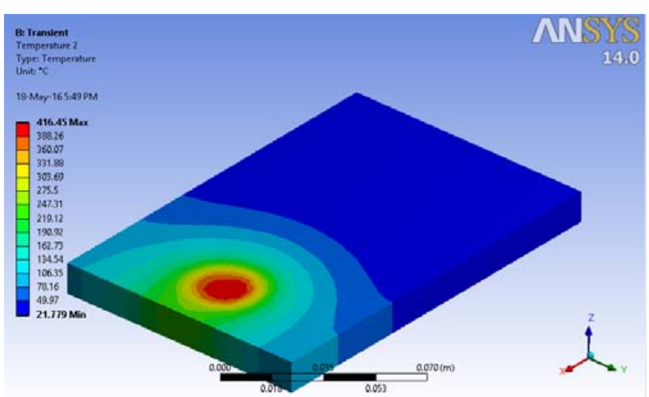


Fig-11 Temperature variation w.r.t distance from edge at tool rotational speed 900 RPM.



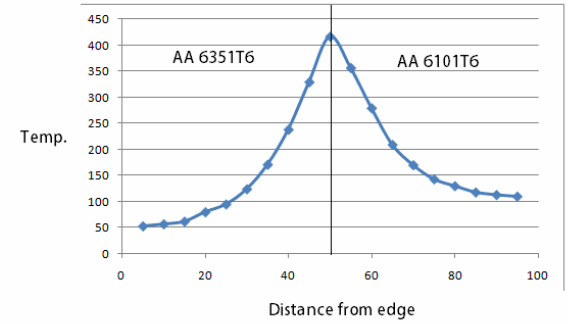
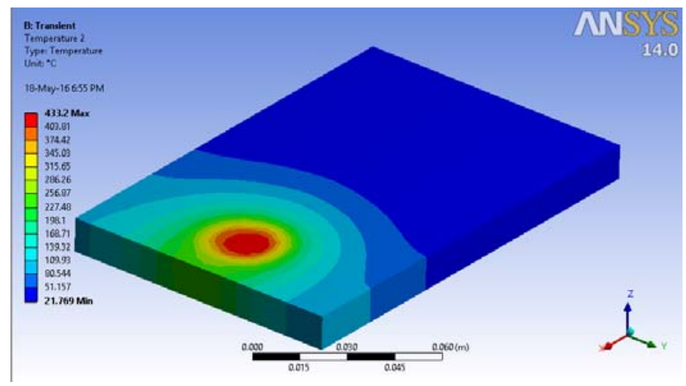


Fig-12. Temperature variation w.r.t distance from edge at tool rotational speed 1000 RPM.



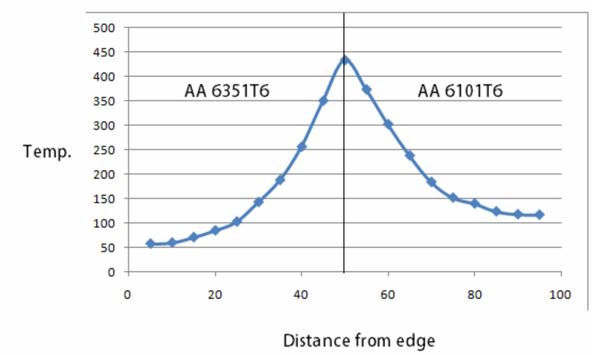
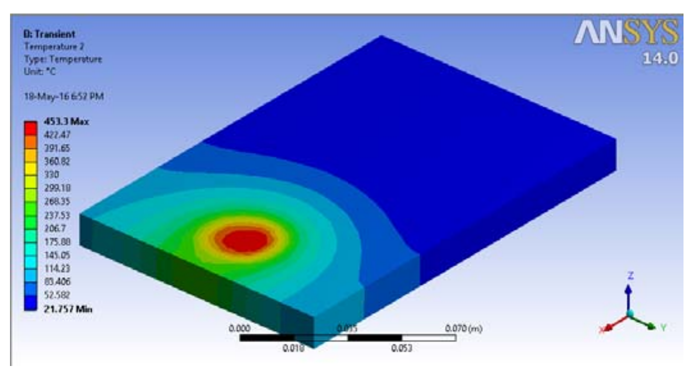


Fig-13. Temperature variation w.r.t distance from edge at tool rotational speed 1100 RPM.



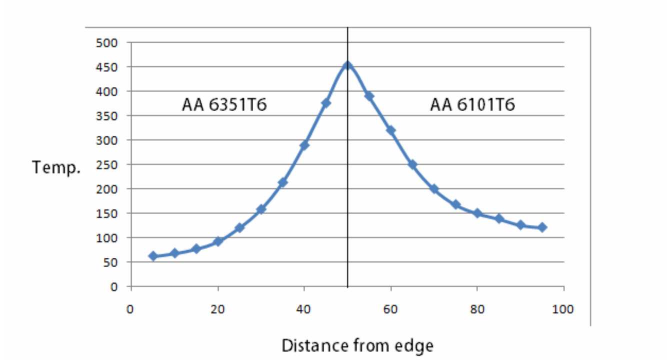


Fig-14. Temperature variation w.r.t distance from edge at tool rotational speed 1200 RPM.

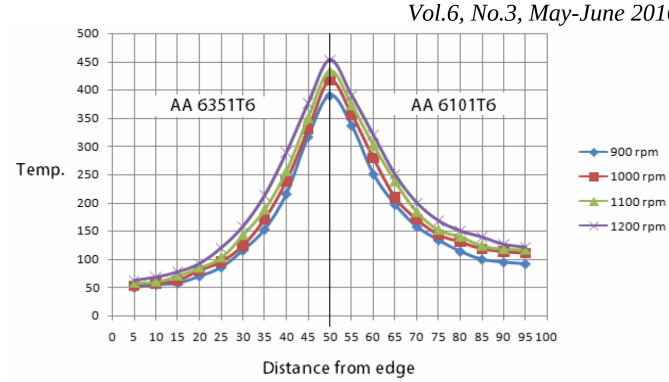


Fig-15 Temperature variation w.r.t distance from weld edge at tool rotational speed 900,1000,1100,1200 RPM.

Table-8 Results for temperature w.r.t distance from edge at rotational speed 900,1000,1100,1200 rpm.

Distance from edge (mm)	Temperature (°C)			
	900rpm	1000 rpm	1100 rpm	1200 rpm
5	50	53	58	62
10	55	57	60	68
15	58	62	71	77
20	70	80	85	92
25	86	95	103	120
30	116	124	143	158
35	153	171	188	213
40	216	238	256	289
45	317	329	350	376
50	390	416	433	453
55	337	356	373	390
60	251	279	302	320
65	197	209	238	250
70	158	170	184	200
75	134	143	152	168
80	114	130	140	150
85	100	118	124	139
90	95	113	118	126
95	92	110	117	121

Table-9 Variation of peak temperature at different rotational speed.

Rotational speed (rpm)	Maximum temperature (°C)
900	390
1000	416
1100	433
1200	453

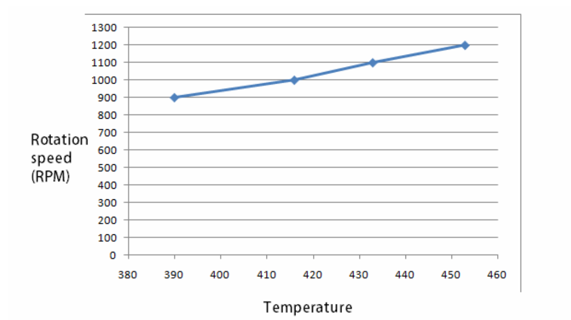


Fig-16 Peak Temperature variation w.r.t tool rotational speed.

IV. CONCLUSION

1. With the use of simulation the analysis can be done much affordably. Once it is setup it takes much lesser time for analysis. Also there is huge reduction in cost as well. The ANSYS software is used to take part in this analysis it also show the validated result.
2. As one moves away from welded region towards the edge the temperature gradually decreases. The result also indicates that the temperature at advanced side is higher than retreat side.
3. As the rotational speed of tool increases temperature also increases. where the temperature linearly increases with increase in rotational speed.
4. There is a shift in the curve, this is due to different material. As thermal conductivity of AA 6101T6 is more than AA 6351T6, its temperature rises more easily, hence an asymmetric curve can be seen.

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