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"Effect of Tool Geometries on Thermal and Mechanical Behaviour of Friction Stir Welding Welds of Aluminum Alloy"

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ABSTRACT : *Friction stir welding is an advanced solid state joining technique, widely being used in various applications for joining aluminum alloys in aerospace, marine, automotive and many other applications of profitable importance. The welding parameters and tool pin profile play a major role in deciding the weld quality. It is an attempt to being made to analyze the effect of tool geometries, the effect of tool rotation and welding speeds on the mechanical properties of friction stir welded joints made for sample of profitable grade aluminum alloy and ANSYS is used to compare and prove the attempts made for various analyses.*

Keywords –*Welding parameters, Tool geometry, ANSYS, Thermal & Mechanical behaviour, FSW*

I. INTRODUCTION

Friction stir welding is the solid state joining process. It is a simple, clean and innovative joining technology for light metals created by The Welding Institute (TWI), England, and U.K. in 1991. Due to the high strength of FSW joints, it allows substantial weight savings in lightweight construction matched to conventional joining technologies. The friction stir welding works on the principle of a rotating pin emergent from a cylindrical shoulder which is plunged between two parts and moved forward along the joint line. The material is heated by rubbing between the rotating shoulder and the work piece surface and at the same time stirred by the profiled pin leaving a solid phase bond between the two bits to be joined. Special preparation of the weld seam and filler wires is not required.

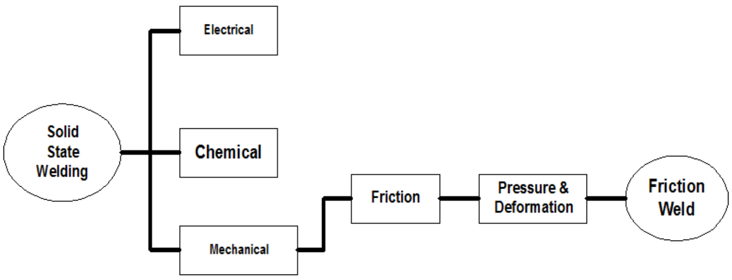


Fig-1: Welding process

Friction welding is a solid-state combination process that create small amount of heat developed between two surfaces by mechanically induces surface movement. Friction stir welding (FSW) is a solid-state welding process in which incomes used for welding do not exceed their melting points. In this procedure the heat generated during interaction in the center of the tool and substrate is used to weld the material in recent times, focus has been on developing fast effectual processes that are atmosphere friendly to join two different materials. The spotlight has been twisted on Friction stir welding as a joining technology able of providing welds that do not have defects usually associated with fusion welding procedures .Friction stir welding (FSW) is an honestly recent technique that utilizes a non useable rotating welding tool to produce frictional heat and plastic deformation at the welding location, thereby disturbing the creation of a joint while the material is in the solid state.

1.1 FSW Process

The working principle of Friction Stir Welding process is show in fig.no.1.1 the FSW process utilize a rotating tool to perform the welding process. The rotating tool consists of minor pin (probe) underneath a larger shoulder. The tool work for three primary functions, that is, heating of the workpiece, progress of material to products the joint and containment the hot metal under the tool shoulder. In FSW, revolving shouldered tool plunges hooked on the joining point of plates and the heat is in the beginning developed from the friction in the middle of the welding tool (including the shoulder and the probe) and the welded material, which cause the welded material to soften at a high temperature less than its melting point. The tool shoulder restrictbecome softer material inferior to the shoulder is further leads to movement of material from the face of the pin to the back of the pin through the rotational and transverse engagements of tool. It is predictable that this process will characteristically produce a weld with less residual stress and misrepresentation as compared to the fusion welding methods, since no soft of the material occurs during the welding.

1.2 FSW PARAMETERS

FSW involves complex material movement and plastic distortion. Welding parameters, Tool geometry and joint design exert important effect on the material movement pattern and temperature distribution, thereby impelling the micro structural evolution of material so, welding speed, the tool rotational speed, the tilt angle of the tool, tool material and the tool design are the main unrestricted variables that are used to control the FSW process.

- Rotational speed
- Welding speed
- Tilt diameter
- Pin length
- Axial force
- Shoulder diameter

(a) Rotational speed

For FSW, two parameters are very important: tool rotation rate (v, rpm) in round or counter circular direction. The motion of the tool generates frictional warm within the work pieces, extruding the softened plasticized material approximately it and forging the same in place so as to form a solid-state joint.

(b) Welding speed

The welding speed depends on some factors, such as alloy type, rotational speed penetration depth, and joint type. Advanced tool rotation rates produce higher temperature because of higher friction heating and result in more intense thrilling and mixing of material. During pass through, softened material from the leading edge interchanges to the trailing edge due to the tool rotation and the traverse drive of the tool, and this transferred material, are coagulate in the trailing edge of the tool by the application of an axial force.

(c) Tool tilt angle

In addition to the tool rotation rate and traverse speed, additional important process parameter is the angle of spindle or tool tilt with reverence to the work piece surface. Appropriate tilt of the spindle towards trailing direction confirms that the shoulder of the tool hold the stirred material in threaded pin and move material efficiently from the forward-facing to the back of the pin. The tool is usually regarded as by a small tilt angle, and as it is injected into the sheets, the blanks material undergoes to a local regressive extrusion process up to the tool shoulder. Promote, the plunge depth of pin into the work pieces (called target depth) is main for producing sound welds with smooth tool shoulders.

(d) Tool design

The success of the FSW procedure depends on the design of the welding tool. The welding tool contains of two features, a pin and the shoulder. Some pin geometries have been proposed, for example a threaded cylinder, a threaded cylinder with fatten sides, etc. a selection of tools designed at TWI. The rotating pin forces the materials to flow around the pin and to mix. The shoulder applies a force to the material to constrain the plasticized material around the pin and generates heat throughout friction and plastic deformation in a relatively thin layer under the shoulder surface. Tool geometry significantly affects the energy input, deformation pattern, plunge force, micro-structures, and mechanical properties of FSW joint. Reviewed and critically observed numerous significant aspects of FSW tools such as tool material collection, geometry and weight bearing ability, mechanisms of tool degradation and process economics. Primary the strength of the material is decrease with increasing temperature due to anise in the shoulder diameter. Second, the area over which the torque is applies enlarge with shoulder diameter. We know that different type of tool geometry.

(e) Tool geometry

Tool geometry affects the heat generation rate, traverse force, torque and the thermo mechanical atmosphere experienced by the tool. The flow of plasticized material in the work piece is pretentious by the tool geometry as well as the linear and rotational movement of the tool. Important factors are shoulder diameter, shoulder surface angle, pin geometry these features are discussed here.

(f) Shoulder diameter

The diameter of the tool shoulder is important as the shoulder generates most of the heat, and its clench on the plasticized materials largely establishes the material flow field. Both sliding and sticking generate heat whereas material flow is caused only from sticking. For a good FSW practice, the material should bead quarterly softened for flow, the tool should have satisfactory grip on the plasticized material and the total torque and traverse force should not be extreme.

(g) Shoulder surface

The nature of the tool shoulder surface is an important aspect of tool design. They establish that triangular pins with concave shoulders resulted in far above the ground strength spot welds. Sorensen and Nielsen86 examined the role of geometric parameters of convex shoulder step spiral (CS4) tools and identified the radius of curvature of the tool shoulder and pitch of the step spiral as important geometric parameters. Microstructure, geometry and failure mode of a weld may be significantly altered if the tool shoulder chosen is concave rather than flat showed that the shoulder surface angle have an effect on the axial force depending on the tool pin radius. A convex shoulder with scrolls was shown to improve FSW process stability. It was argue that what time a convex scroll shoulder is used in constant axial force mode, any raise in plunge depth from its normal value results in greater make contact with area between the shoulder and the workpiece. As a result, the axial pressure is packed jointly and the plunge depth decrease to its original value. Similarly, any reduce in the plunge depth lower the shoulder/workpiece make contact with area resultant in advanced axial pressure and a consequent revisit of the plunge depth to its common value. Therefore, the FSW process with convex scroll shoulder tends to be stable with a nearly constant plunge depth. All found that the convex scroll shoulder resulted in minimum flash and no faults as opposite to concave shoulder which resulted in medium flash and some defects. It has been suggested that the conventional rotating shoulder tools can result in high thermal gradient and high horizontal temperatures throughout FSW of low down thermal conductivity alloys leading to deterioration of weld excellence. A stationary shoulder friction stir welding process has been technologically advanced by The Welding Institute in which the non-rotating shoulder slides on the workpiece surface as the rotating pin move forward.

(h) Pin geometry

The shape of the tool pin (or probe) influences the flow of plasticized material and affect weld property. Kumar and Kailas suggested that while the tool shoulder facilitated bulk material flow the pin aided a layer by layer material flow. Figure 3 shows the shapes of some of the commonly used tool pins. A triangular or 'trifluted' tool pin increases the material flow compared with a cylindrical pin the axial force on the workpiece matter and the flow of material near the tool are affected by the orientation of threads on the pin surface. These commonly used pin geometry of tool geometry.

Table -1: Key benefits of FSW

Metallurgical benefits	Environmental benefits	Energy benefits
• Solid phase process.	• No distrustful gas required	• Improved materials use (e.g., joining different thickness) allows reduction in weight
• Low falsification of work piece.	• No surface cleaning required	•Decreased fuel consumption in light weight aircraft automotive and ship applications
•Good dimensional stability and repeatability	• Eliminate grinding wastes	
• Fine microstructure	• Consumable materials save, such as rugs, cable or any other gas	
•Absence of cracking		

II. LITRETURE RIVIEW

Dr. M. Lakshman Rao et al. [1] showed the highpoints the role of tool geometry, because tool geometry plays a major role in FSW. In this research the important result has been identify like Proper selection of a tool material, profile of the pin decreases number of trials and tooling cost. In addition this study also highpoints the wear cause due to friction between descending surfaces.

P.Prasanna et al. [2] discussed the main objective of this article is to discover the optimum operating situations for butt joint complete of aluminium alloy AA6061. Four main controllable reasons each at four levels, namely, rotational speed, welding speed, tool pin length, offset space are considered for the present study. This four are the important as the point of view of the area of the welding.

PuneetRohilla et al. [3] investigated an attempt has been complete to study the effect of tool pin profile (straight cylindrical and square) on the formation of friction stir processing zone in a single and progressive double sided friction stir weld in AA6061. This study also revels the important result related the welded joint of Al 6061.

Basil M. Darras et al. [4] has been discussed about the micro structural modifications technique. Reported results showed that for different alloys and also work on the experimental and logical activity.

B.T. Gibsona et al. [5] concluded that the basic principles of FSW covered terminology, material flow, joint configurations, tool design, materials, and defects. Methods of evaluating weld excellence are surveyed as well. The modern applications are discussed, with a prominence on recent advances in aerospace, automotive, and ship building.

G. Elatharasana et al. [6] has been discussed about that the optimization of the different parameter and developed the mathematical model and study of the analysis.

S.Ugendera et al.[7]founded that the tool material rotational speed have been the impotent parameter and that are effect the stir zone microstructure and properties of friction stir process.

Ashok Kumar et al. [8] discussed on the different parameter of the FSW. In this paper analyzed the joint characteristics of similar and dissimilar materials used in fabrication industries which are difficult to join by other technique. The analysis was completed with the help of ANSYS software computationally & same was experimentally verified.

Patel Chandresh V. [9] resulted research normally lies on characteristics of FSW tool pin's profile on FSW joint. In this work will be carried out using different tool pin profile like tapper cylindrical, square, tapper hexagonal, and threaded cylindrical. Test specimen has been prepared from acquire results and various tests (tensile and bending test) will be carried out to prove its optimal joints. On the basis of these results and parameters used throughout experiment the effect of tool pin profile will be understood.

Tran Hung Tra et al. [10], has been discussed of the Effect of tool rotation speed and welding speed on the mechanical properties of the FSW joint of AA6063-T5 was investigated. It was also found that the residual stress in and around the welded zone was quite low, in range of ten percent.

III. RESEARCH METHODOLOGY

3.1 SELECTION OF WORK-PIECE MATERIAL

Aluminium alloy is one of the most widely used materials in all industrial applications and accounts for approximately half of the world's aluminium production and use. Because of its aesthetic view in architecture, superior physical and mechanical properties, resistance aligned with corrosion and chemicals, weld ability; it has become the most preferred material over others. These are mostly used to manufacture temperature resistant products. The dimension of specimen in the range of the length = 240mm, thickness = 5mm, and width = 60mm

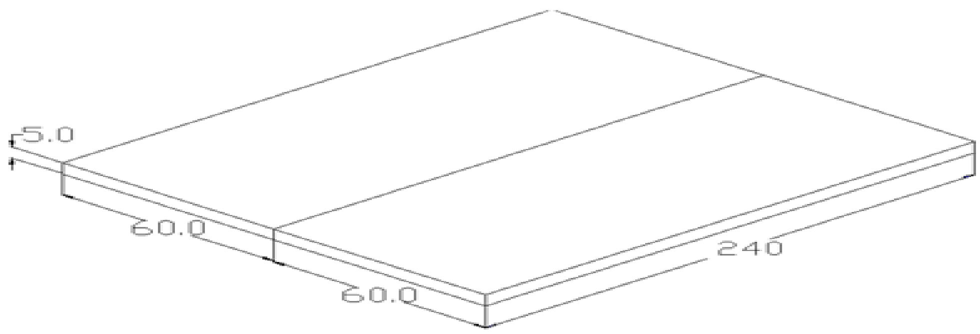


Fig-2: Specimen of work-pieces

Table-2: Mechanical Properties of aluminum alloy

Property	**Symbols**	**Unit**	**Value**
Density	ρ	kg/m^3	2.71×10^3
Ultimate tensile strength	T	Mpa	310
Young modules	E	Gpa	71
Poisson ratio	μ		0.33
Thermal conductivity	K	W/m.k	175

3.2 SELECTION OF TOOL MATERIAL

The simulation was conducted using friction stir welding. We know that different type of tool is available this time and there we are using different type of tool geometry on different tool material. We are using two type tool materials viz (a) SS316 and (b) Carbon steel 1095

(a) Stainless steel 316

The mechanical properties of Stainless Steel 316Are given below-

Table-3: Mechanical Properties of SS 316

Property	Unit	Value
Density	g/cm^3	7.99
Ultimate tensile strength	Ksi	75
Yield strength	Ksi	30
Hardness of 20% temp.	HRC	95
Thermal conductivity	W/M.K	16.2

(b) Carbon Steel 1095
The mechanical properties of Carbon Steel 1095 are given below

Table-4: Mechanical properties of carbon steel 1095

Property	Unit	Value
Density	g/cm^3	7.85
Thermal conductivity(k)	w/m^2	350
Thermal expansion coefficient		6.7
Tensile strength	Mpa	685
Yield strength	Mpa	525
Elongation		97

3.3 SELECTION OF TOOL DESIGN PARAMETER

Friction stir welding are tool design is a important factor for welding.some impotant parameter are shown there.

- Rotational speed
- Welding speed
- Pin length
- Tilt angle
- Pin diameter
- Tool shoulder
- Ratio of diameter
- Tool profile

3.4 SELECTION OF TOOL GEOMETRY

- In friction stir welding are different types of tool geometries are applicable and to analyze the effect we selected two geometries namely straight cylindrical, tapered cylindrical with threaded.

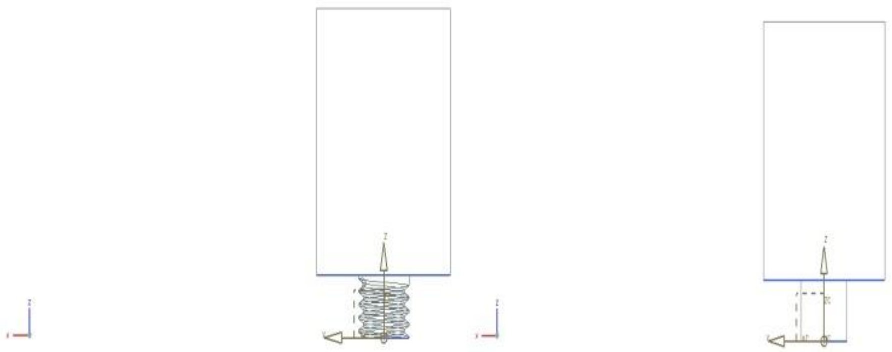


Fig-3: The schematic diagram of (a) Tapered cylindrical with threaded (b) straight cylindrical Tool geometry

FSW parameters and tool nomenclature is shown in Table-5 are taken for experimental work.

Table-5: FSW process parameters and tool nomenclature

Parameters	Value
Rotational speed(rpm)	410,635
Welding speed(mm/min)	75,190
Pin length(mm)	4.7
Tilt angle	2.5
Pin diameter(mm)	6
Tool shoulder(mm)	16
D/d Ratio of tool(mm)	2.6
Tool materials	SS 316,Carbon Steel1095
Axial force(KN)	5
Tool Profile	Tapered with Threaded Cylindrical, Straight Cylindrical

3.5 ANALYSIS TECHNIQUES

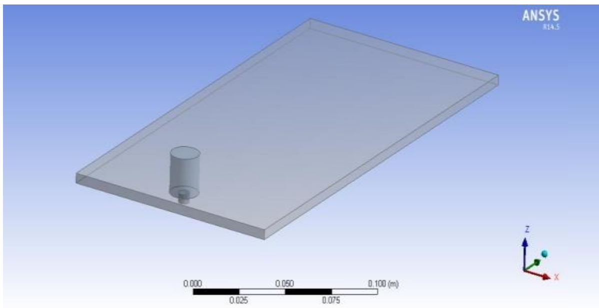
There are various analysis methods are available; in this work finite element method is adopted for analysis. To implement this method FEA package is used namely ANSYS software.

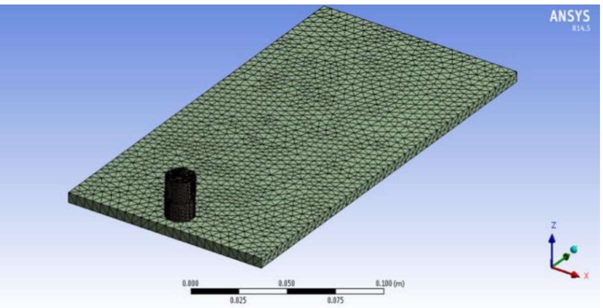
3.6 EVALUATION OF ANALYSIS WORK

Finite element analysis of friction stir welding tool by using ANSYS. There we are using the workpiece material of aluminium alloy plate and tool material is different. We will perform the thermal analysis of the tool geometry's are.

- Straight cylindrical tool
- Tapered threaded cylindrical tool

3.7 CAD MODEL OF PLATE





(A) (B)

Fig-4: (A) CAD model of the tool and plate (B) Meshing of the plate and tool

Number of element = 46724

Number of nodes = 7157

The plate of the material aluminum alloy is taken for the research work with dimension of 240×60×5 mm the CAD model of plate along with the tool geometry is draw with the help of ANSYS software represents the geometry and dimension of the plate and tool .

Table-6: Plate Dimension

Parameter	Value
Length	240 mm
Width	60 mm
Thickness	5 mm

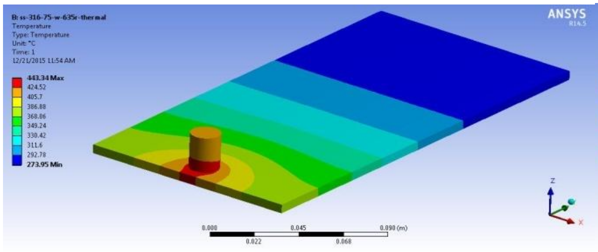
.

IV. RESULTS

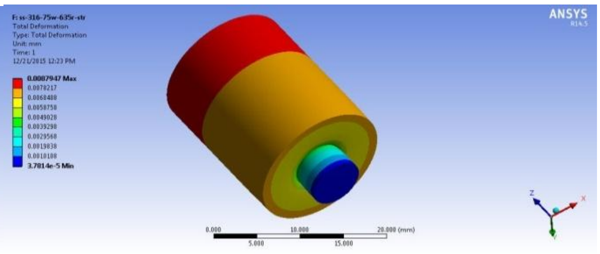
Thermal temperature generated on the friction stir welding straight cylindrical tool geometry.

Tool material-SS316

For straight cylindrical tool following boundary conditions are applied on tool pin and shoulder for a welding speed 75mm/min analysis is done for first rotational speed 635rpm. To Analyse the effect of thermal and mechanical behaviour of selected material of aluminium alloy. Thermal and mechanical behaviour after applying boundary condition are shown in Fig-5 (a) temperature distribution range, (b) deformation, (c) von-mises-stress (mpa) are 443.34°C to 273.95min, 8.79E-03, and 0.601 to 211.58mpa respectively.

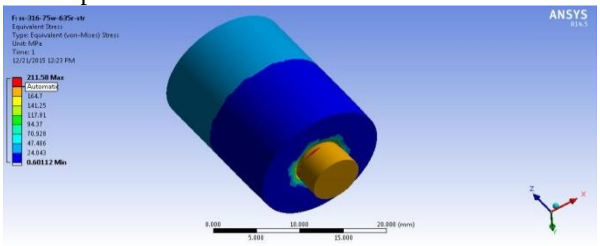


(a)



(b)

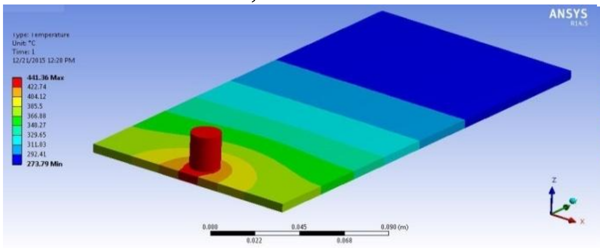
Fig-5:(a) Thermal temp. (b) Deformation (c) Von-mises stress, of SS316, welding speed = 75, rotational speed = 635 rpm



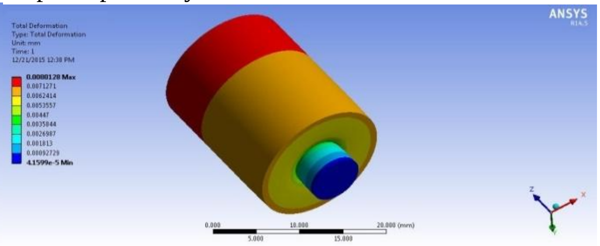
(c)

Tool material carbon1095

Straight cylindrical tool following boundary condition are applied on tool pin and shoulder for a welding speed 75mm/min analysis is done for rotational speed 635rpm . To analyse the effect of thermal and mechanical behaviour of selected material of aluminium alloy. Thermal and mechanical behaviour after applying boundary condition are shown in Fig-6 (a) temperature distribution range ,(b) deformation,(c) vonmises-stress (mpa) are 273.79̊C to 441.36̊C,8.01E-03mm and 0.62 to 206.68 mpa respectively.



(a)



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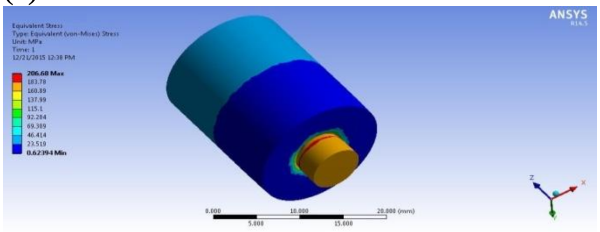


(c)

Fig-6: (a) Thermal temperature (b) deformation (c)) vonmises-stress (mpa),of Carbon Steel 1095 welding speed = 75, rotational speed = 635 rpm

Table-7: Comparison of straight cylindrical tool temperature generated tool material of SS316, carbon-1095

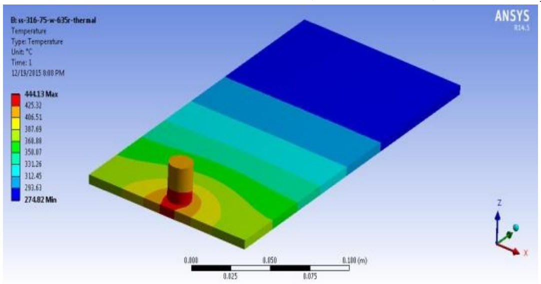
Tool geometry type	Material	Welding speed (mm/min)	Rotational speed(rpm)	Max. Temp. (˚C)
Straight Cylinder Tool	SS316	75	410	295.13
			635	443.34
		190	410	133.07
			635	191.06
	Carbon Steel1095	75	410	294.49
			635	442.35
		190	410	132.79
			635	190.66

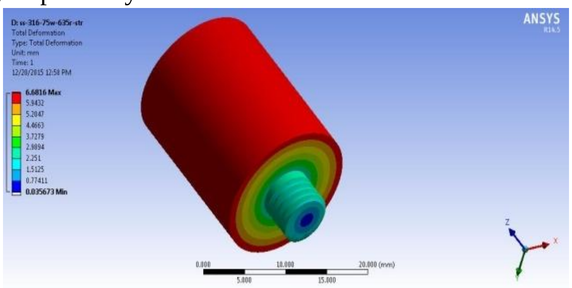
Table-8: Structural analysis of straight cylindrical tool geometry for tool material of SS316 and Carbon Steel-1095

Tool geometry type	Tool material	Welding speed	Rotational speed	Mass(KN)	Deformation(mm)	Von-mises stress(mpa)
Straight Cylinder Tool	SS-316	75	410	0.03323	8.79E-03	211.58
			635	0.03323	8.79E-03	211.58
		190	410	0.03323	8.79-03	211.58
			635	.03323	8.79-03	211.58
	Carbon-1095	75	410	0.03261	8.01E-03	206.68
			635	0.03261	8.01E-03	206.68
		190	410	0.03261	8.01E-03	206.68
			635	0.03261	8.01E-03	206.68

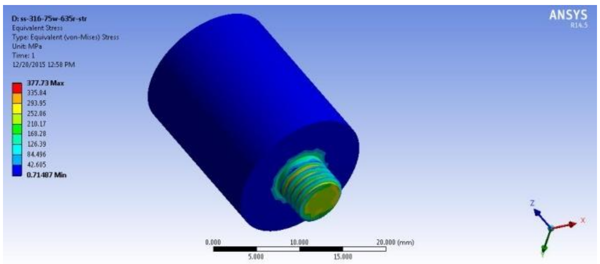
Thermal temperature generated on the friction stir welding tapered threaded straight cylindrical tool Tool material SS316

Tapered threaded straight cylindrical tool following boundary condition are applied on tool pin and shoulder for a welding speed 75mm/min analysis is done for rotational speed 635rpm.To analysed the effect of thermal and mechanical behaviour of select work of aluminium alloy. Thermal and mechanical behaviour after applying boundary condition are shown in Fig-7 (a)temperature distribution range,(b) deformation, (c)von-mises-stress (mpa) are 274.82°C TO 444.13°C,6.6816mm,377.73 mpa, respectively.

(a)




(b)

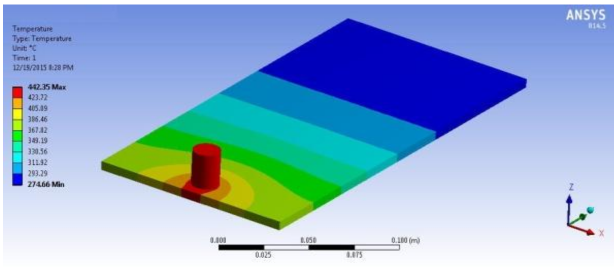


(c)

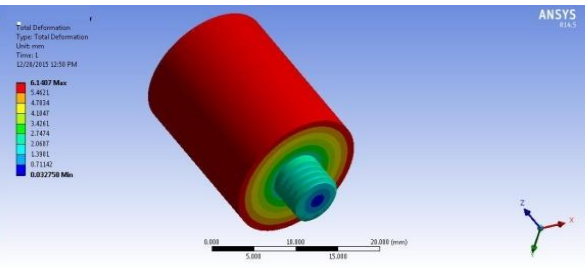
Fig-7(a) Thermal temp.(b)Deformation(c)von-mises stress ,of Welding speed = 75, rotational speed = 635 rpm,SS316

Tool material carbon 1095

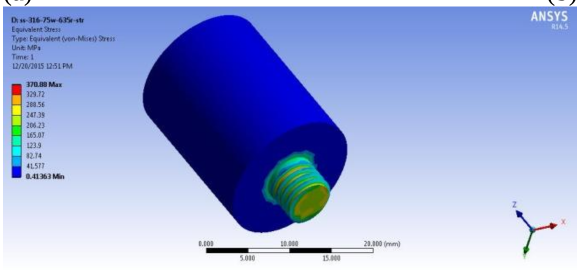
Tapered threaded straight cylindrical tool following boundary condition are applied on tool pin and shoulder for a welding speed 75mm/min analysis is done for rotational speed 635rpm.To analysed the effect of thermal and mechanical behaviour of select work of aluminium alloy. Thermal and mechanical behaviour after applying boundary condition are shown (a)temperature distribution range, (b)deformation, (c)von-mises-stress (mpa) are 274.66°C to 442.35°C,6.1407mm ,370.88mpa, respectively.



(a)



(b)



(c)

Fig-8(a) Thermal temp.(b)Deformation (c) Von-mises stress, of Carbon Steel1095, rotational speed = 635, welding speed = 75mm/min

Table-9: Thermal analysis of tapered threaded cylinder tool geometry for tool material of SS316 and Carbon Steel1095.

Tool geometry type	Material	Welding speed (mm/min)	Rotational speed(rpm)	Max. Temp. (◌̊C)
Tapered Threaded cylindrical tool	SS316	75	410	295.64
			635	444.13
		190	410	133.27
			635	191.36
	Carbon Steel1095	75	410	294.49
			635	442.35
		190	410	132.79
			635	190.66

Table-10: Structural analysis of tapered threaded cylinder tool geometry for tool material of SS316 and Carbon Steel-1095.

Tool geometry type	Material	Welding speed (mm/min)	Rotational speed (mm/min)	Mass	Deformation (mm)	vonmises-stress mpa
Tapered threaded cylinder tool	SS316	75	410	0.03307	6.6816	377.73
			635	0.03307	6.6816	377.73
		190	410	0.033	6.6816	377.73
			635	0.33	6.6816	377.73
	Carbon1095	75	410	0.032	6.1407	370.88
			635	0.032	6.1407	370.88
		190	410	0.032	6.1407	370.88
			635	0.032	6.1407	370.88

V. CONCLUSION

In this study analysis of effects of tool geometries on thermal and mechanical behaviour during welds of aluminium alloy on friction stir welding was carried out. In this work two tool geometries were taken, first one is straight cylindrical tool geometry; second one is tapered threaded cylindrical tool geometry. Analysis was successfully completed and obtained acceptable results, optimal results for SS316 tool material for both geometries are 75mm/min and 635 rpm were obtained which gives maximum temperature and acceptable von-mises-stress. . The values are useful for manufacturing industry using friction stir welding.

Table-11: optimal values of straight cylindrical and threaded cylindrical tool for thermal analysis

Tool geometry type	Tool material	Welding speed (mm/min)	Rotational speed (rpm)	Max. Temp. (˚C)
Straight cylindrical tool	SS316	75	635	443.34
	Carbonsteel1095	75	635	441.36
Tapered threaded cylindrical	SS316	75	635	444.13
	Carbon steel1095	75	635	442.35

Table-12: optimal values of straight cylindrical and tapered threaded cylindrical tool for structural analysis

Tool geometry type	Tool material	welding speed (mm/min)	Rotational speed (rpm)	Mass (kg)	Deformation (mm)	Vonmises-stress (mpa)
Straight cylinder	SS316	75	635	0.33	8.79E-03	211.58
	Carbon1095	75	635	0.03261	8.01E-03	206.68
Tapered Threaded cylindrical tool	SS 316	75	635	0.03307	6.6816	377.73
	Carbon1095	75	635	0.03245	6.1407	370.88

Table-13: optimal values of tool material SS316 straight cylindrical and threaded cylindrical tool for structural analysis

Tool geometry type	Tool material	welding speed (mm/min	Rotational speed (rpm)	Mass (kg)	Deformation (mm)	Vonmises-stress (mpa)
Straight cylindrical	SS316	75	635	0.33	8.79E-03	211.58
Tapered Threaded cylindrical tool	SS 316	75	635	0.03307	6.6816	377.73

Table-14: optimal values of tool material SS316 straight cylindrical and threaded cylindrical tool for thermal analysis

Tool geometry type	Tool material	welding speed (mm/min)	Rotational speed(rpm)	Max. Temp(C)
Straight cylindrical	SS316	75	635	443.34
Tapered Threaded cylindrical	SS316	75	635	444.13

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