Thermal Analysis of Friction Stir Welding

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***Abstract*—Friction stir welding is a solid state joining process where the metal is not melted. It is used when the original metal characteristics must remain unchanged as much as possible. It mechanically intermixes the two pieces of the metal at the place of the join, then softens them so the metal can be fused using mechanical pressure, much like joining clay, dough or plasticine. It is primarily used on aluminium, and most often on large pieces that cannot be easily heat treated after welding to recover temper characteristics.**

In the present work, Finite Element Analysis is performed for Friction Stir Welding of Aluminium and Copper. The welds are produced by varying the process parameters viz., the rotational speed at 900 revolutions per minute and the welding speed varied between 60 mm/min and 80 mm/min. Then Thermal analysis is performed. A parametric model with the plates and cutting tool is done in Creo-2.

The effects of different tool pin profiles on the friction stir welding are also considered for analysis. Different tool pin profiles are square and circular. For this purpose we created a simple model of Friction stir welding tool and two work pieces to be joined by butt joint using Creo software and Thermal analysis is done on them.

***Keywords*— Friction Stir welding (FSW), Finite Element Analysis, Thermal Analysis.**

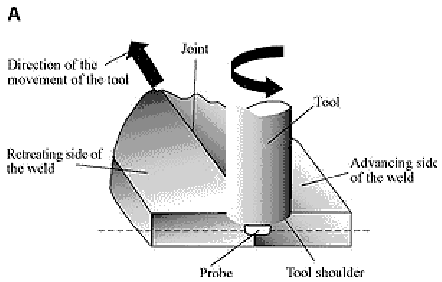
I. INTRODUCTION

Friction stir welding is a solid state joining process where the metal is not melted. It is used when the original metal characteristics must remain unchanged as much as possible. It mechanically intermixes the two pieces of the metal at the place of the join, then softens them so the metal can be fused using mechanical pressure, much like joining clay, dough or plasticine. It is primarily used on aluminium, and most often on large pieces that cannot be easily heat treated after welding to recover temper characteristics.

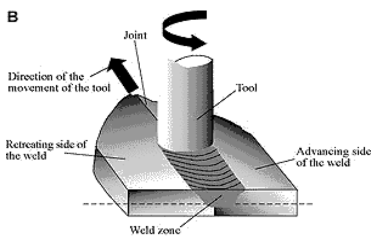
In Friction Stir Welding, a cylindrical tool, with a profiled, threaded or unthreaded probe (nib or pin) is rotated at constant speed and fed at a constant rate into the joint line between two pieces of sheet or plate material, which are butted together. The parts have to be clamped rigidly onto a backing bar in a manner that prevents the abutting joint faces from being forced apart. The length of the nib I slightly less than the weld depth required and the tool shoulder is in intimate contact with the work surface. The nib is then moved against the work, or vice versa. Frictional heat is generated between the wear resistant welding tool shoulder and nib, 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 it's a solid state welding). 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 a substantial forging force to consolidate the weld metal. The welding of the material is facilitated by severe plastic deformation in the solid state, involving dynamic recrystallization of the base material.

FSW is used as the main engine for the calculation of stresses and temperatures. The model does not consider the transient variations of variables during the initial tool insertion period or the final tool withdrawal period. The model does solve the equations of conservation of mass, momentum and energy in steady state, three-dimensional Cartesian coordinate considering incompressible single phase flow. It calculates the three dimensional heat generation rtes, temperature and velocity fields, viscosity, flow stress, strain rate and torque for various welding conditions and tool and work piece materials. Since the details of the model are already available, only the extension of the heat transfer and materials flow model to calculate the bending and maximum shear stresses are discussed.

A. Principle of Operation-Initial state of the plates



B. During the stir welding in progress



II. THREE DIMENSIONAL MODELING

In our project we have designed 3D models of the tool and the weld plates using PTC Creo software. Creo is a family or suite of design software supporting product design for discrete manufacturers and is developed by PTC. PTC Creo is a scalable, interoperable suite of product design software that delivers fast time to value. It helps teams create, analyze, view and leverage product designs downstream utilizing 2D CAD, 3D CAD, parametric & direct modeling.

PTC Creo Parametric provides the broadest range of powerful yet flexible 3D CAD capabilities to accelerate the product development process. By automating tasks such as creating engineering drawings, we are able to avoid errors and save significant time. The software also lets us perform analysis, create renderings and animations, and optimize productivity across a full range of other mechanical design tasks, including a check for how well our design conforms to best practices. PTC Creo Parametric enables us to design higher-quality products faster and allows us to communicate more efficiently with manufacturing, suppliers.

In our present work we considered two dissimilar metals viz Aluminium 6061 and Copper to perform Stir welding on them, with two pin profile of the Tool viz Circular and Square. The stir welding is considered at a tool rotational speed of 900RPM, the tool is traversed at 80 mm/min and 60 mm/min for each profile of the tool tip. For this purpose we created 3D models of the weld plates of both the metals to be joined and the tool profiles with which the stir welding is performed, with the following specifications

Length of the plate	= 100mm
Width of the plate	= 30mm
Diameter of the large cylinder	= 15mm
Diameter of the small cylinder	= 5mm
Length of the cylinder	= 50mm
Length of the square tool	= 5mm

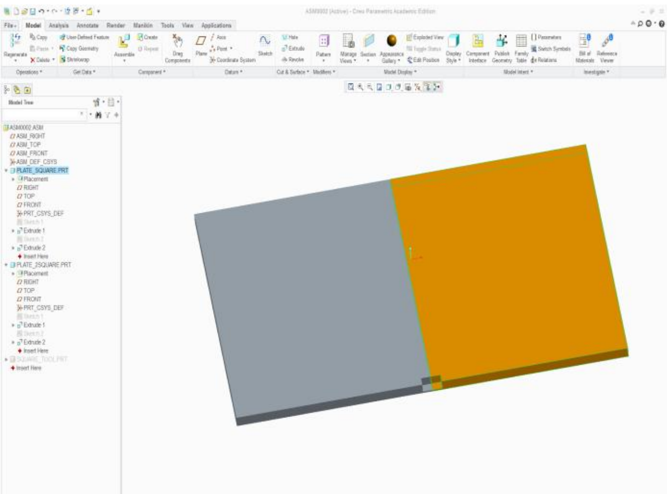


Fig. 1. 3D Modeling of plates to be welded (Al and Cu).

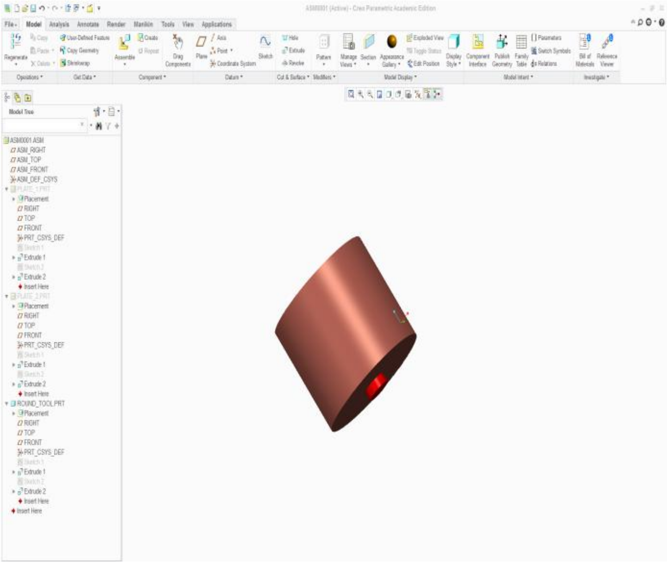


Fig. 2. 3D Modeling of Round Tool

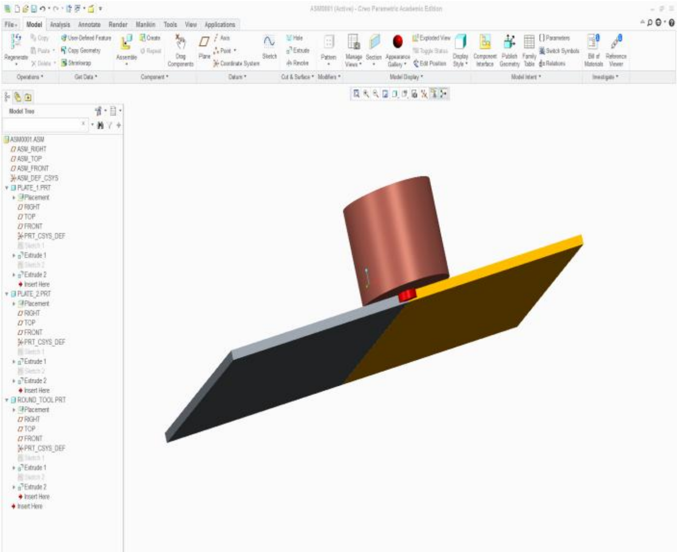


Fig. 3. 3D Model of round tool and weld plates assembly

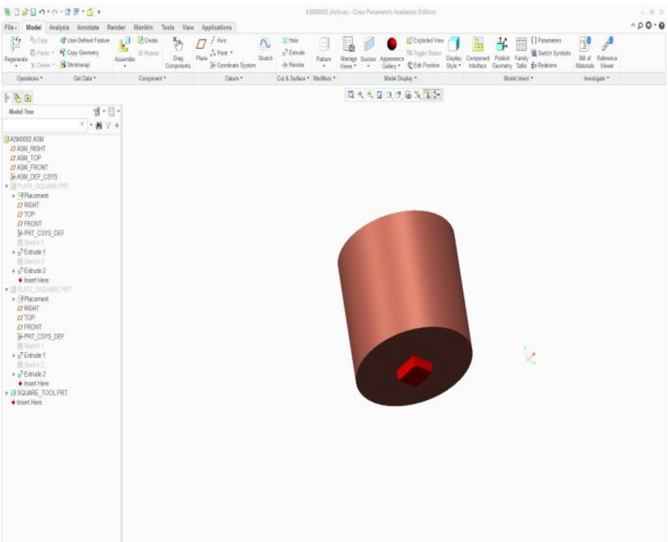


Fig. 4. 3D Modeling of Square Tool

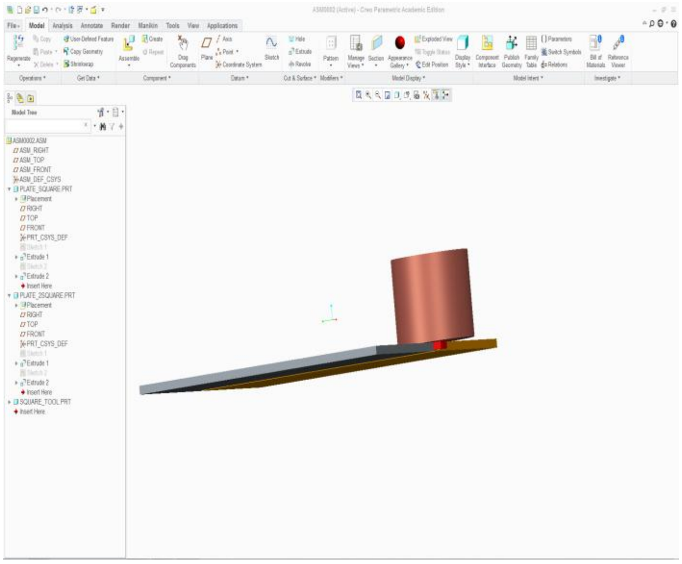


Fig. 5. 3D Model of round tool and weld plates assembly

III. ANALYSIS OF THE WELD PLATES

The above 3D models of the weld plates are imported in to the ANSYS for analysis purpose. The analysis is done as per the following criteria

TABLE 1

Tool Revolution-900rpm	round tip	square tip
Traverse speed (mm/minute)	80	80
	60	60

The Analysis of the Geometry is performed is as follows-

A. For the Round Tool tip revolving at 900 RPM and Traverse speed of 80 mm/min.

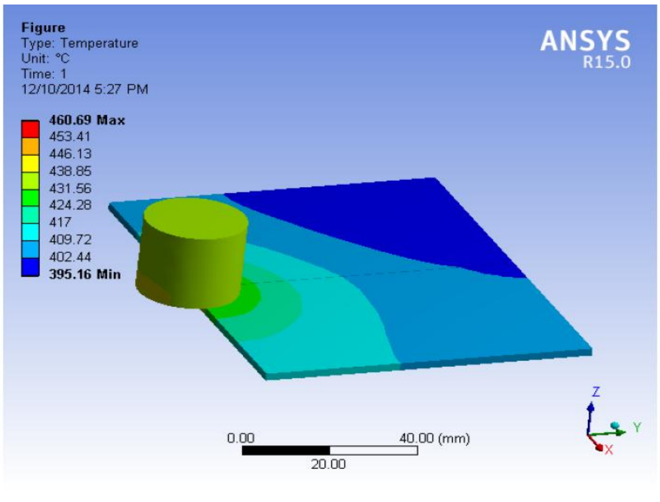


Fig. 6. Temperature on weld plates

From the above figure, the temperature distribution on the weld plates is obtained. The blue color indicates the lowest temperature zone which is 395.16 °C and red colour, which was below the tool, ie at the tool tip indicates the maximum temperature zone which is 460.69 °C.The intermediate temperatures are obtained in the middle range indicated by different colors in the graph.

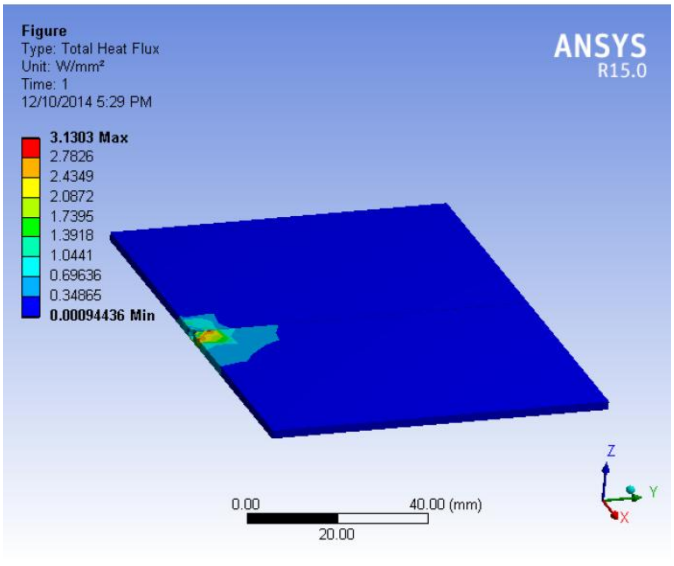


Fig. 7. Total heat flux

From the above figure, the total heat flux on the weld plates is obtained. The blue color indicates the area of lowest heat flux which is 0.00094436 W/mm^2 and red colour indicates the area of maximum heat flux which is 3.1303 W/mm^2. The intermediate values of total heat flux on the weld plates are obtained in the middle range indicated by different colors in the graph.

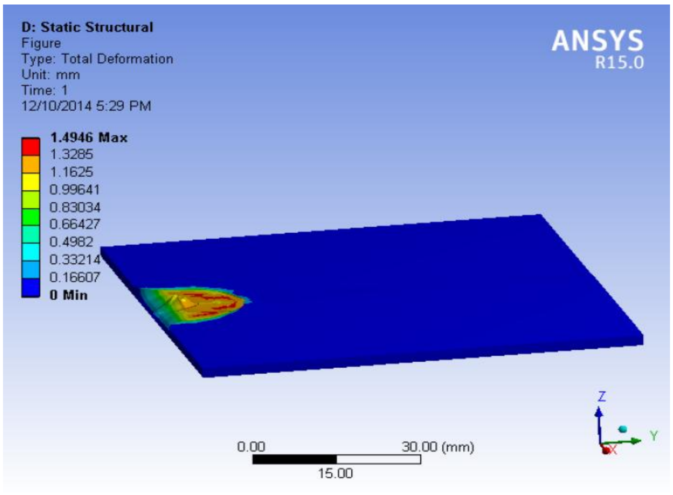


Fig. 8. Total deformation of welded plate.

From the above figure, the total deformation of the welded plates is obtained. The blue color indicates the area of lowest deformation and red colour indicates the area of maximum total deformation which is 1.4946 mm. The intermediate values of total deformation of the welded plates are obtained in the middle range indicated by different colors in the graph.

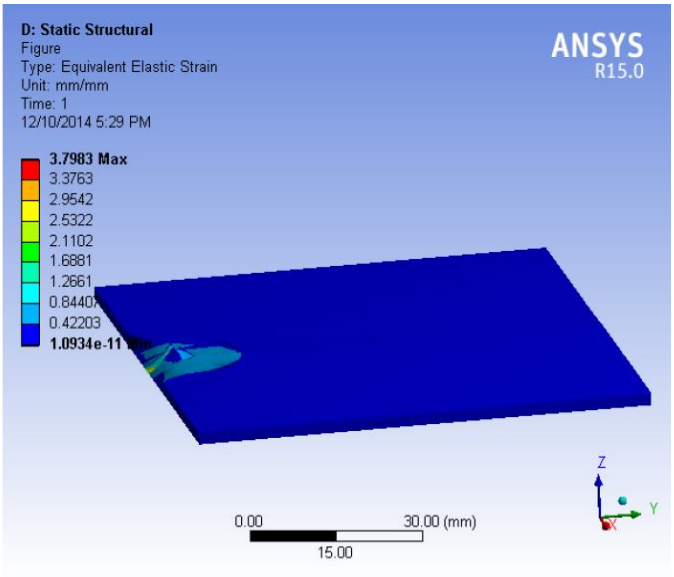


Fig. 9. Equivalent Elastic Strain

From the above figure, the values of equivalent elastic strain on the welded plates is obtained. The blue color indicates the area of lowest equivalent elastic strain which is 1.0934 x 10^{-11} and red colour indicates the area of maximum equivalent elastic strain which is 3.7983. The intermediate values of total equivalent elastic strain of the welded plates are obtained in the middle range indicated by different colors in the graph.

B. Analysis for the Square Tool tip revolving at 900 RPM and Traverse speed of 60 mm/min.

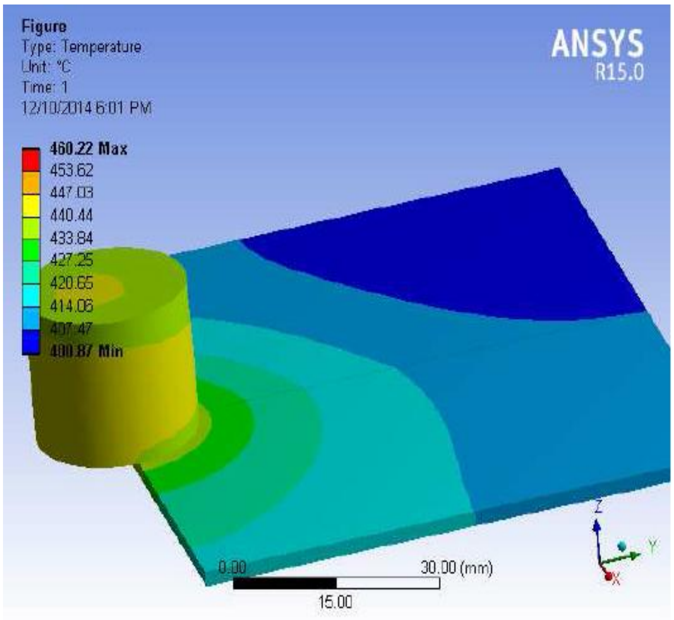


Fig. 10. Temperature on weld plates

From the above figure, the temperature distribution on the weld plates is obtained. The blue color indicates the lowest temperature zone which is 400.87 °C and red colour which was below the tool, ie at the tool tip indicates the maximum temperature zone which is 460.22 °C.The intermediate temperatures are obtained in the middle range indicated by different colors in the graph

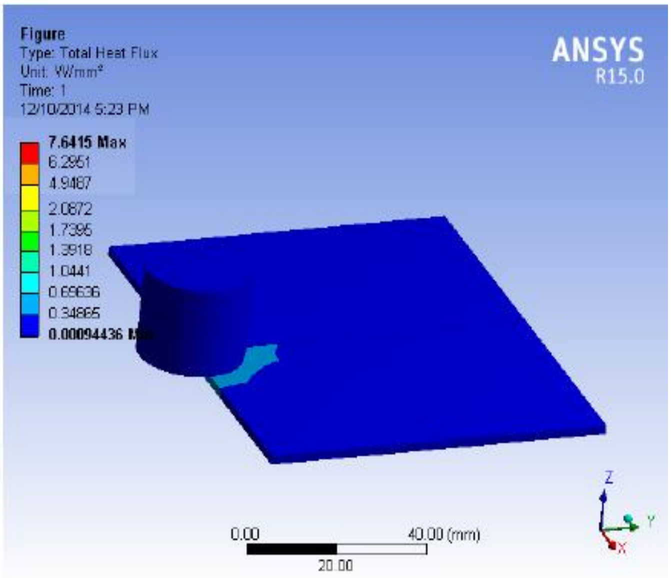


Fig. 11. Total Heat Flux on the welded plates.

From the above figure, the total heat flux on the weld plates is obtained. The blue color indicates the area of lowest heat flux which is 0.00094436 W/mm^2 and red colour indicates the area of maximum heat flux which is 7.6415 W/mm^2. The intermediate values of total heat flux on the weld plates are obtained in the middle range indicated by different colors in the graph.

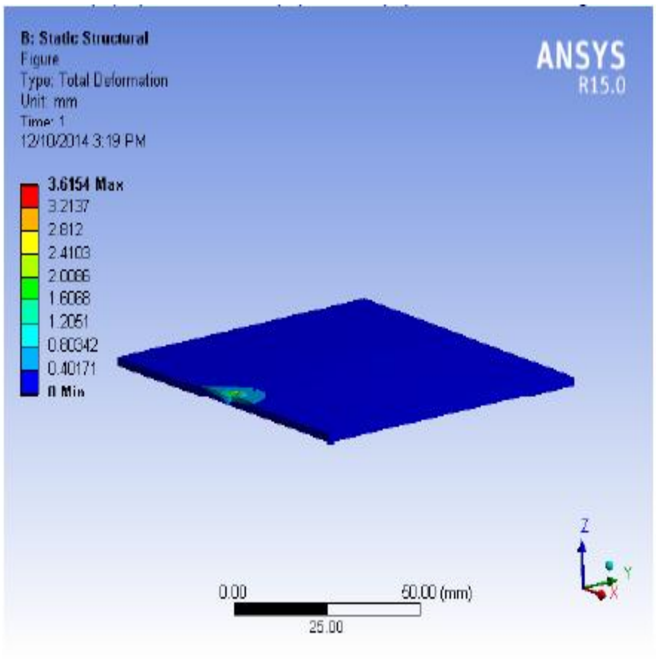


Fig. 12. Total Deformation on the welding plates.

From the above figure, the total deformation of the welded plates is obtained. The blue color indicates the area of lowest deformation, where there is no deformation and red colour indicates the area of maximum total deformation which is 3.6154 mm. The intermediate values of total deformation of the welded plates are obtained in the middle range indicated by different colors in the graph.

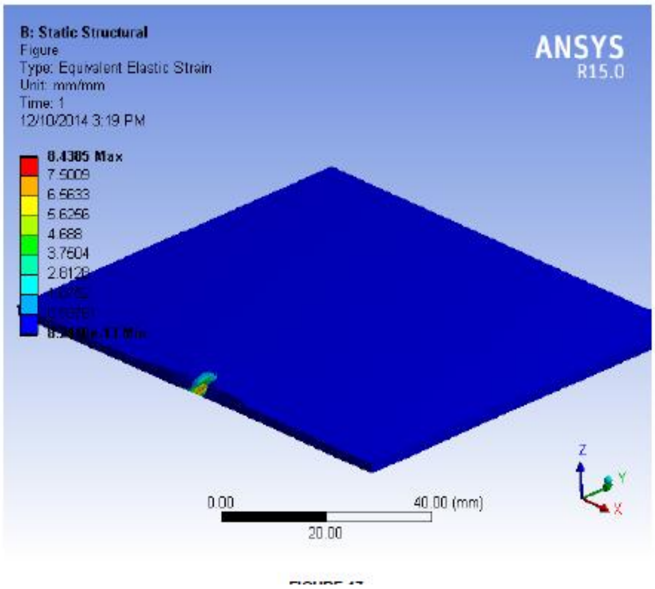


Fig. 13. Equivalent Elastic strain on the welding plates.

From the above figure,the values of equivalent elastic strain on the welded plates is obtained. The blue color indicates the area of lowest equivalent elastic strain which is 8.022 x 10^{-13} and red colour indicates the area of maximum equivalent elastic strain which is 8.4385. The intermediate values of total equivalent elastic strain of the welded plates are obtained in the middle range indicated by different colors in the graph.

In a similar fashion the Thermal Analysis was performed for both round and square tool tips at traverse speeds of 60 mm/min and 80 mm/min.

IV. RESULTS

TABLE 2

Tool Traverse Speed (mm/min)	Round Tool Tip		Square Tool Tip	
	80	***60***	***80***	***60***
Temperature (°C)	460	460	460	460
Total Heat Flux (W/mm^2)	3.13	2.45	9.56	7.64
Total Deformation (mm)	1.49	1.12	4.48	3.61
Equivalent Elastic Strain	3.79	2.84	9.43	8.43

The probe (tool tip) shape plays an important role in friction stir welding process, here we have considered two types of probes viz., cylindrical (round) and square profiles. It is observed that, proper diffusion of material in the weld zone has taken place when using cylindrical profile tool. This is due to the increase in surface area in contact between the tool and the work piece. The proper diffusion of the material results in better mechanical properties. It is also observed that the surface finish obtained also depends on the probe shape and the shoulder area. Fine surface is obtained when the shoulder is in contact with the work piece.

The fabrication of cylindrical tool was easier compared to square tool. The initial penetration of the cylindrical tool was difficult at the start of the weld. The vibration of the machine at the start of the weld with this tool was relatively high. Apart from high initial vibration of the machine, the straight cylindrical tool exhibited good weld surface finish and overall acceptable welds. It is observed that the cylindrical tool of 5mm diameter with minimum flat shoulder contact surface produces welds with good mechanical properties. The maximum diameter of the cylindrical tool considered was 7 mm as a tool probe diameter exceeding 7 mm did not produce an acceptable weld.

V. CONCLUSIONS

- 3D modelling of the work plates and weld tool tips are produced and imported successfully for joining two dissimilar metals Aluminium-6061 and copper.
- Finite Element Analysis is done on round and square profile tool tips.
- From the Thermal Analysis temperature distribution, thermal flux, and stresses at different traverse speeds are obtained.
- From the results it is observed that thermal flux and thermal gradient are more for square tool than the round tool.
- Temperature produced is sufficient for obtaining melting points of the plates.
- From FEA analysis it is evident that round tip is more preferable than the square tip, in friction stir welding.

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