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Investigation of Thermal Field in Friction Surfacing Different Tool Pin Profiles Square and Circular

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ABSTRACT:

Friction-stir welding (FSW) is a solid-state joining process (the metal is not melted) and is used when the original metal characteristics must remain unchanged as much as possible. It mechanically intermixes the two pieces of 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 aluminum, and most often on large pieces that cannot be easily heat-treated after welding to recover temper characteristics. In this project, FEA analysis is performed for friction stir welding of aluminum and copper. The welds are produced by varying the process parameters; the rotational speed was varied between 600 to 1200 rpm and the welding speed varied between 50 and 300 mm/min. Structural and thermal analysis are done. A parametric model with the weld 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. So in this project we want to create simple model of FSW tool and two work pieces to be joined by butt by using Creo workbench and also analysis the working pieces that is effected by the thermal stress that are applied on it.

Keywords: Aluminum, copper, Friction-stir welding (FSW), mechanical pressure, thermal stress.

INTRODUCTION:

Friction-stir welding (FSW) is a solid-state joining process (meaning the metal is not melted during the process) and is used for applications where the original metal characteristics must remain unchanged as far as possible. This process is primarily used on aluminum, and most often on large pieces which cannot be easily heat treated post weld to recover temper characteristics.

PRINCIPLE OF OPERATION

Schematic diagram of the FSW process: (A) Two discrete metal work pieces butted together, along with the tool (with a probe). The progress of the tool through the joint, also showing the weld zone and the region affected by the tool shoulder. In FSW, a cylindrical-shouldered tool, with a profiled threaded/unthreaded probe (nib or pin) is rotated at a constant speed and fed at a constant traverse 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 is slightly less than the weld depth required and the tool shoulder should be 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 cited a solid-state process), allowing the traversing of the tool along the weld line in a plasticized tubular shaft of metal. 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.

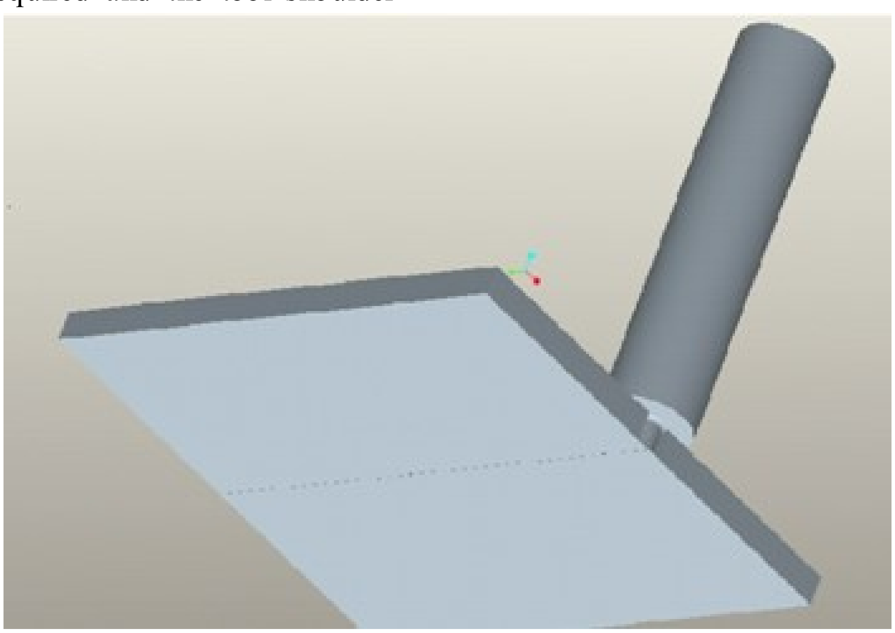

Figure 1: 3-D Model of Friction Surfacing

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 solves the equations of conservation of mass, momentum and energy in steady-state, three-dimensional Cartesian coordinate considering incompressible single phase flow. It calculates three dimensional heat generation rates, 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 in the literature,6-12 these are not repeated here. Instead, only the extension of the heat transfer and materials flow model to calculate the bending and maximum shear stresses are discussed here.

$$\frac{da}{dN} = A\Delta K^{m} \quad (1)$$

$$\Delta K = \Delta\sigma(\pi a)^{1/2} \quad (2)$$

$$N_f = [a_f^{(1-m/2)} - a_0^{(1-m/2)}]/[A(1-m/2)\Delta\sigma^{m}\pi^{0.5m}] \quad (3)$$

$$a_f = [K_I/(1.12\tau_b)]^2/\pi \quad (4)$$

$$\sigma_B = \frac{4\cos\theta}{\pi r^3}\int_{z_1}^{L} z\, q(z)\, dz \quad (5)$$

$$\tau_T = \frac{M_T}{\pi r^3/2} \quad (6)$$

$$M_T = \oint_A r_A \times (1-\delta)\ \tau \ \times dA \quad (7)$$

Where MT is the sticking torque, rA is the distance of any infinitesimal area element, dA, from the tool axis, ' is the spatial fractional slip, % is the temperature dependent shear strength. The shear stress, %B, at point A due to bending can now be computed as

$$\tau_B = \frac{4}{3}\frac{\sin^2\theta}{\pi r^2}\int_{z_1}^{L} q(z)\, dz \quad (8)$$

$$\tau_{max} = \sqrt{\left(\frac{\sigma_B}{2}\right)^2 + (\tau_B + \tau_T \sin\theta)^2 + (\tau_T \cos\theta)^2} \quad (9)$$

TOOL ROTATION AND TRAVERSE SPEEDS

There are two tool speeds to be considered in friction-stir welding; how fast the tool rotates and how quickly it traverses the interface. These two parameters have considerable importance and must be chosen with care to ensure a successful and efficient welding cycle. The relationship between the welding speeds and the heat input during welding is complex but, in general, it can be said that increasing the rotation speed or decreasing the traverse speed will result in a hotter weld. In order to produce a successful weld it is necessary that the material surrounding the tool is hot enough to enable the extensive plastic flow required and minimize the forces acting on the tool. If the material is too cool then voids or other flaws may be present in the stir zone and in extreme cases the tool may break. At the other end of the scale excessively high heat input may be detrimental to the final properties of the weld. Theoretically, this could even result in defects due to the liquation of low-melting-point phases (similar to liquation cracking in fusion welds). These competing demands lead onto the concept of a 'processing window': the range of processing parameters that will produce a good quality weld. Within this window the resulting weld will have a sufficiently high heat input to ensure adequate material plasticity but not so high that the weld properties are excessively reduced.

TOOL TILT AND PLUNGE DEPTH

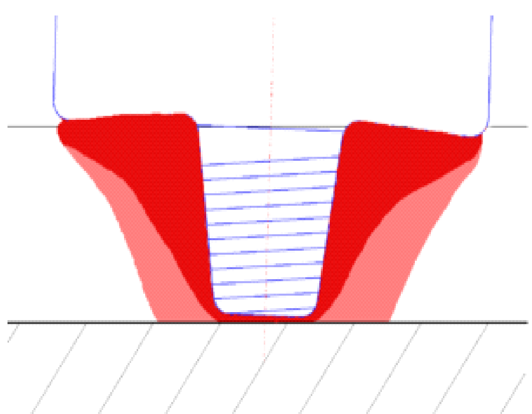

Figure 2: A drawing showing the plunge depth and tilt of the tool

The tool is moving to the left.

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The plunge depth is defined as the depth of the lowest point of the shoulder below the surface of the welded plate and has been found to be a critical parameter for ensuring weld quality. Plunging the shoulder below the plate surface increases the pressure below the tool and helps ensure adequate forging of the material at the rear of the tool. Tilting the tool by 2-4 degrees, such that the rear of the tool is lower than the front, has been found to assist this forging process. The plunge depth needs to be correctly set, both to ensure the necessary downward pressure is achieved and to ensure that the tool fully penetrates the weld. Given the high loads required the welding machine may deflect and so reduce the plunge depth compared to the nominal setting, which may result in flaws in the weld. On the other hand an excessive plunge depth may result in the pin rubbing on the backing plate surface or a significant under match of the weld thickness compared to the base material. Variable load welders have been developed to automatically compensate for changes in the tool displacement while TWI have demonstrated a roller system that maintains the tool position above the weld plate.

TOOL DESIGN

The design of the tool is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed. It is desirable that the tool material is sufficiently strong, tough and hard wearing, at the welding temperature. Further it should have a good oxidation resistance and a low thermal conductivity to minimize heat loss and thermal damage to the machinery further up the drive train. Hot-worked tool steel such as AISI H13 has proven perfectly acceptable for welding aluminium alloys within thickness ranges of 0.5 – 50 mm but more advanced tool materials are necessary for more demanding applications such as highly abrasive metal matrix composites or higher melting point materials such as steel or titanium.

Improvements in tool design have been shown to cause substantial improvements in productivity and quality. TWI has developed tools specifically designed to increase the depth of penetration and so increase the plate thickness that can be successfully welded. An example is the ‘whorl’ design that uses a tapered pin with re-entrant features or a variable pitch thread in order to improve the downwards flow of material. Additional designs include the Triflute and Trivex series. The Triflute design has a complex system of three tapering, threaded re-entrant flutes that appear to increase material movement around the tool. The Trivex tools use a simpler, non-cylindrical, pin and have been found to reduce the forces acting on the tool during welding. The majority of tools have a concave shoulder profile which acts as an escape volume for the material displaced by the pin, prevents material from extruding out of the sides of the shoulder and maintains downwards pressure and hence good forging of the material behind the tool. The Triflute tool uses an alternative system with a series of concentric grooves machined into the surface which are intended to produce additional movement of material in the upper layers of the weld.

GENERATION AND FLOW OF HEAT

For any welding process it is, in general, desirable to increase the travel speed and minimize the heat input as this will increase productivity and possibly reduce the impact of welding on the mechanical properties of the weld. At the same time it is necessary to ensure that the temperature around the tool is sufficiently high to permit adequate material flow and prevent flaws or tool fracture. When the traverse speed is increased, for a given heat input, there is less time for heat to conduct ahead of the tool and the thermal gradients are larger. At some point the speed will be so high that the material ahead of the tool will be too cold and the flow stress too high, to permit adequate material movement, resulting in flaws or tool fracture. If the 'hot zone' is too large then there is scope to increase the traverse speed and hence productivity.

The welding cycle can be split into several stages during which the heat flow and thermal profile will be different:

- **Dwell**. The material is preheated by a stationary, rotating tool in order to achieve a sufficient temperature ahead of the tool to allow the traverse. This period may also include the plunge of the tool into the work piece.
- **Transient heating**. When the tool begins to move there will be a transient period where the heat production and temperature around the tool will alter in a complex manner until an essentially steady-state is reached.
- **Pseudo steady-state**. Although fluctuations in heat generation will occur the thermal field around the tool remains effectively constant, at least on the macroscopic scale.
- **Post steady-state**. Near the end of the weld heat may 'reflect' from the end of the plate leading to additional heating around the tool.

Heat generation during friction-stir welding arises from two main sources: friction at the surface of the tool and the deformation of the material around the tool. The heat generation is often assumed to occur predominantly under the shoulder, due to its greater surface area, and to be equal to the power required to overcome the contact forces between the tool and the workpiece. The contact condition under the shoulder can be described by sliding friction, using a friction coefficient μ and interfacial pressure P, or sticking friction, based on the interfacial shear strength &tor; at an appropriate temperature and strain rate. Mathematical approximations for the total heat generated by the tool shoulder Q_{total} have been developed using both sliding and sticking friction models:

$$Q_{total} = \frac{2}{3}\pi P \mu \omega \left(R^3_{shoulder} - R^3_{pin}\right) \text{(Sliding)}$$

$$Q_{total} = \frac{2}{3}\pi \tau \omega \left(R^3_{shoulder} - R^3_{pin}\right) \text{(Sticking)}$$

Where ω is the angular velocity of the tool, $R_{shoulder}$ is the radius of the tool shoulder and R_{pin} that of the pin. Several other equations have been proposed to account for factors such as the pin but the general approach remains the same.

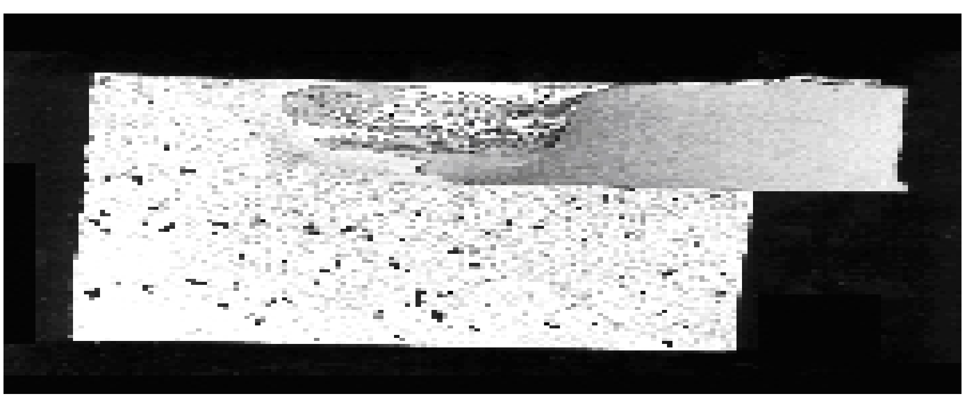
A major difficulty in applying these equations is determining suitable values for the friction coefficient or the interfacial shear stress. The conditions under the tool are both extreme and very difficult to measure. To date, these parameters have been used as 'fitting parameters' where the model works back from measured thermal data to obtain a reasonable simulated thermal field. While this approach is useful for creating process models to predict, for example, residual stresses it is less useful for providing insights into the process itself.

MATERIALS AND THICKNESSES

Friction stir welding can be used for joining many types of materials and material combinations, if tool materials and designs can be found which operate at the forging temperature of the work pieces.

For aluminium alloys, the following alloys are easily welded. Maximum thickness in a single pass is dependent on machine power, but values ≥50mm are achievable. TWI has welded 75mm 6xxx material in a single pass, and larger thicknesses are possible.

- 2000 series aluminium (Al-Cu)
- 5000 series aluminium (Al-Mg)
- 6000 series aluminium (Al-Mg-Si)
- 7000 series aluminium (Al-Zn)
- 8000 series aluminium (Al-Li)



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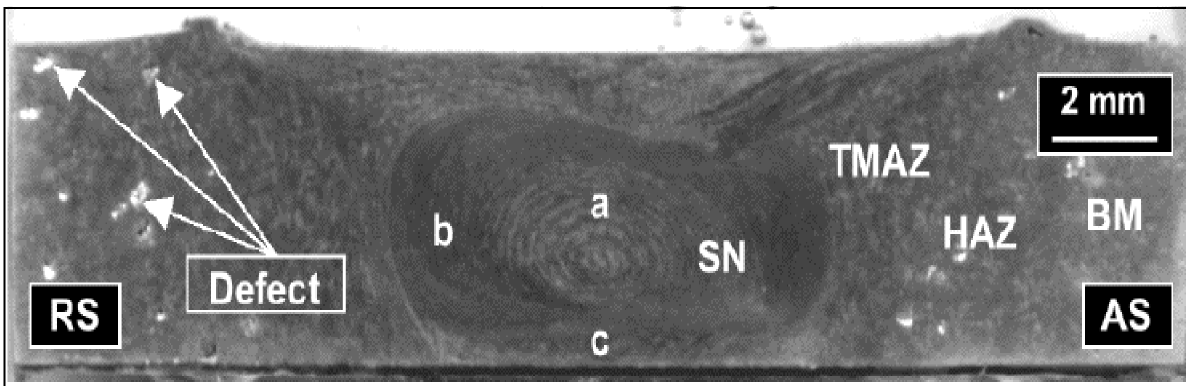
MMCs based on aluminum (metal matrix composites) Other aluminum alloys of the 1000 (commercially pure), 3000 (Al-Mn) and 4000 (Al-Si) series, aluminum castings.

Other materials successfully welded include:

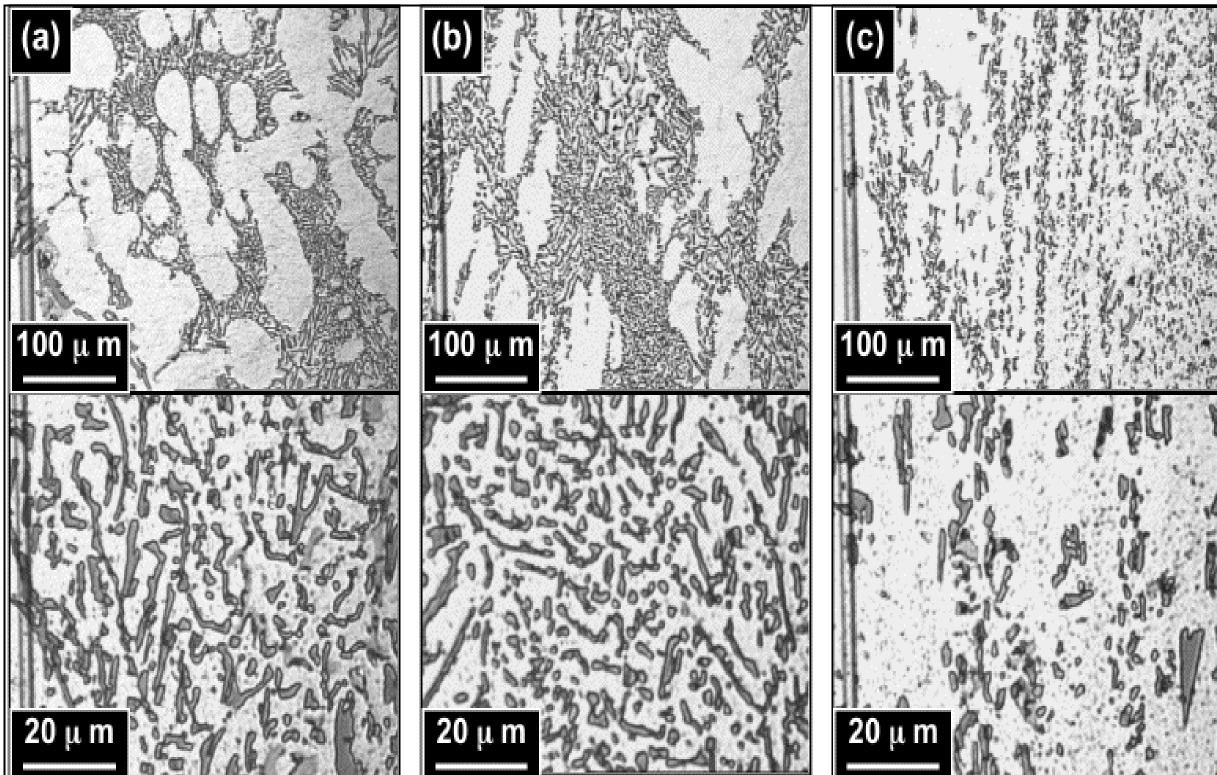
- Copper and its alloys (up to 50mm in one pass)
- Lead
- Titanium and its alloys
- Magnesium alloys
- Zinc
- Plastics
- Mild and C-Mn steels
- Stainless steel (austenitic, martensitic and duplex)
- Nickel alloys

FRICTION STIR WELDING OF CAST ALUMINIUM ALLOY

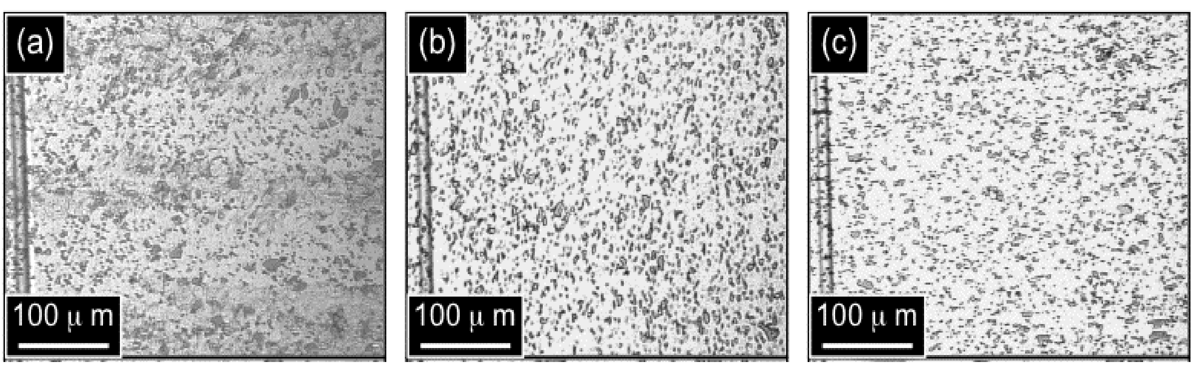
The most popular aluminum casting-alloy contains about 8 wt% of silicon. It therefore solidifies to primary aluminum-rich dendrites and a eutectic mixture of aluminum solid-solution and almost pure silicon. The latter occurs as coarse silicon particles which tend to be brittle. The cast alloy usually has some porosity. Friction stir welding has the advantage that it breaks up the coarse silicon particles and heals any pores by the mechanical processing, as illustrated below.



A section through a friction stir weld made in an Al-Si casting alloy. There are pores indicated in the base metal (BM). HAZ represents the heat affected zone, TMAZ the thermo mechanically affected zone, and SN the stir nugget. The photographs in this section have kindly been provided by Professor H. Fujii of JWRI, Japan.



Optical micrographs showing the microstructure in (a) the base metal; (b) heat-affected zone; (c) the thermomechanically affected zone, where considerable refinement of the silicon has occurred.



Optical micrographs of regions (a), (b) and (c) of the stir nugget. The location of these regions is identified in macroscopic section presented above.

	Tensile strength (MPa)	Proof stress (MPa)	Elongation (%)	Fracture location
Joint	150	85	1.6	BM
Weld	179	87	5.3	TMAZ
SN	251	96	14.4	SN

The refinement of silicon and elimination of porosity leads to better mechanically properties in the weld than in the base plates.

MODELS OF CUTTING TOOLS

ROUND TOOL

PLATE1

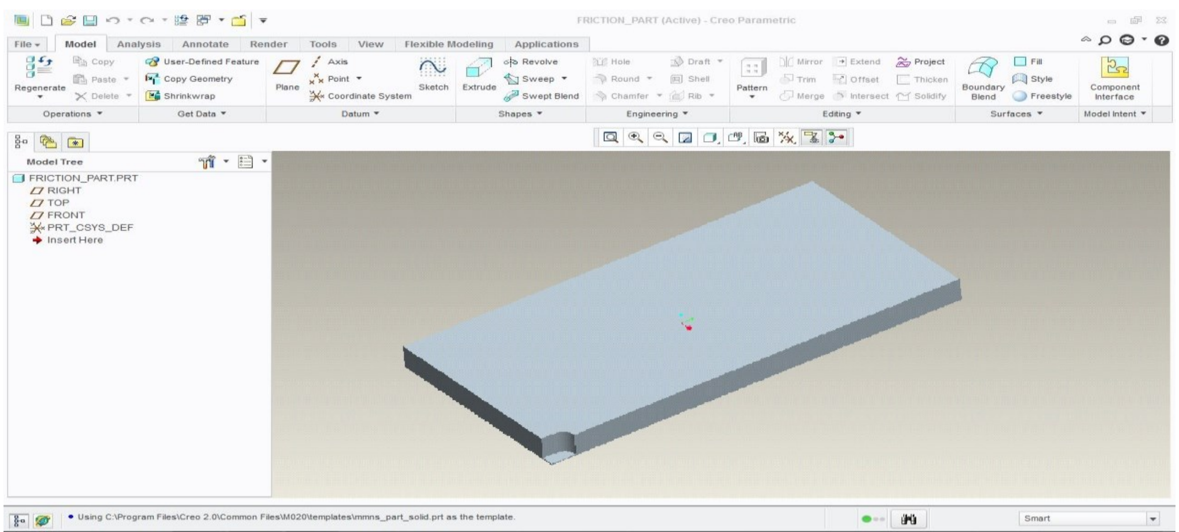


PLATE2

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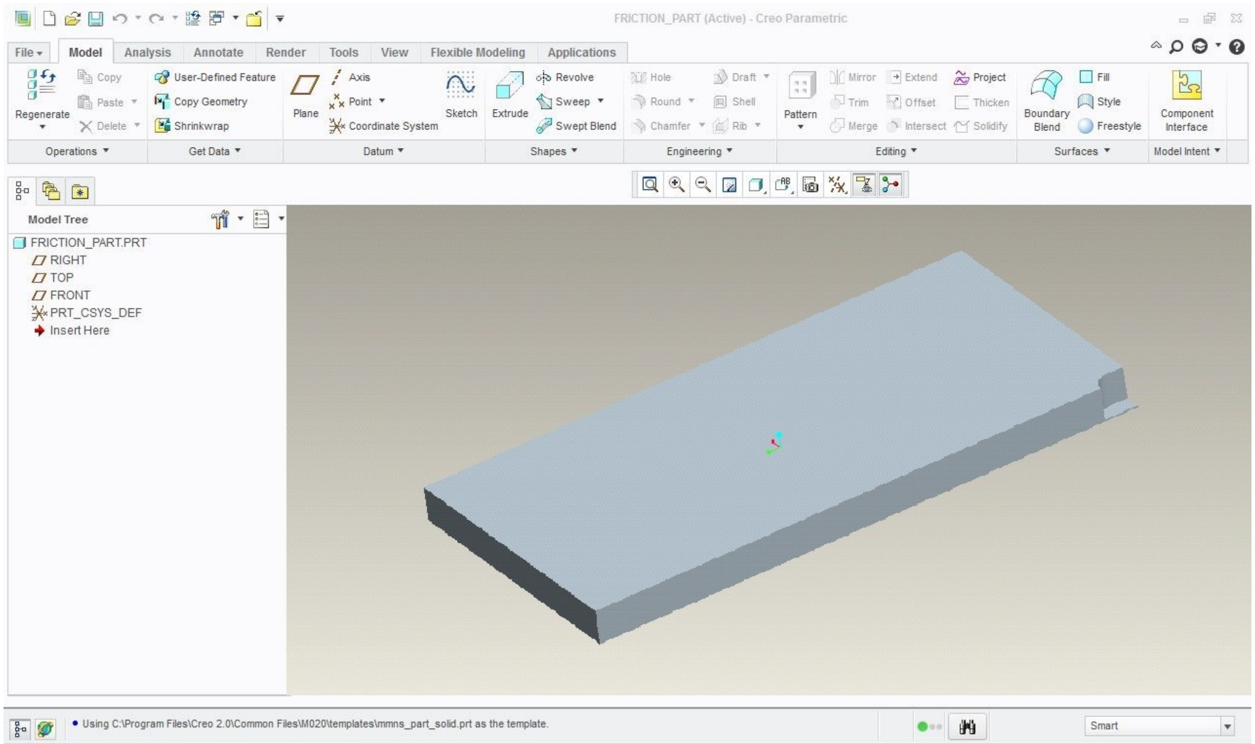
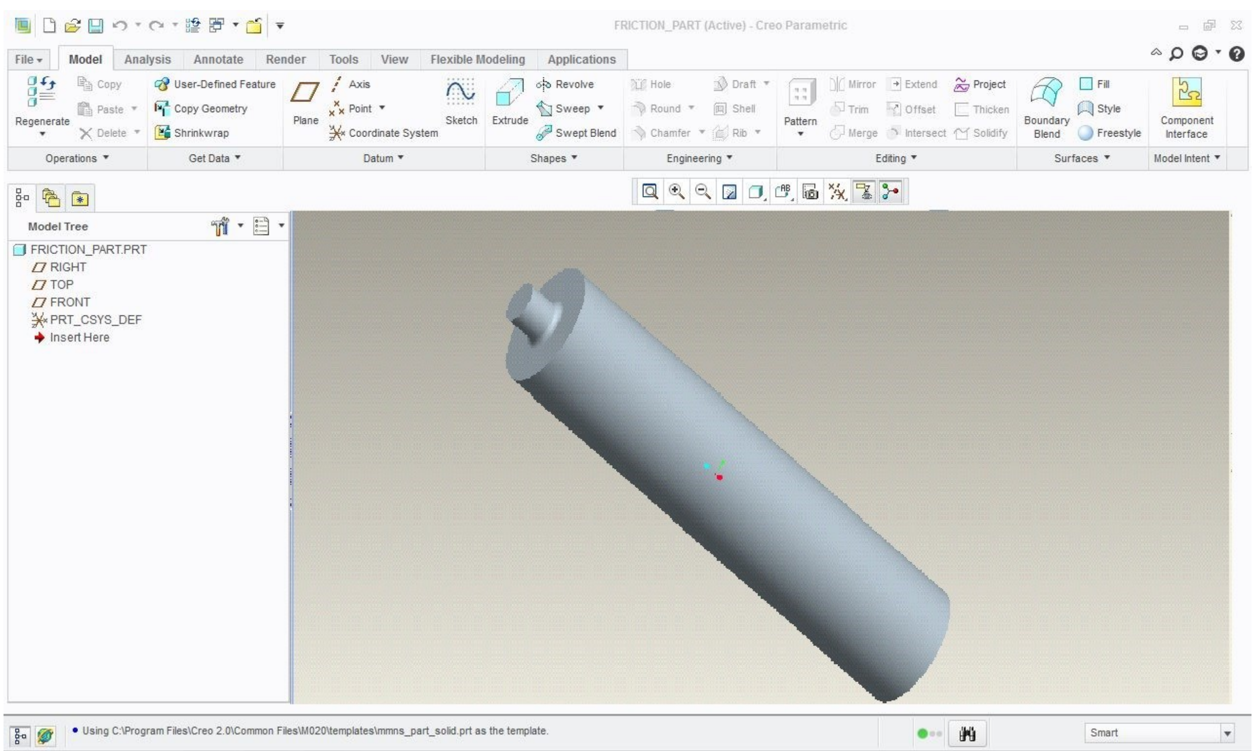
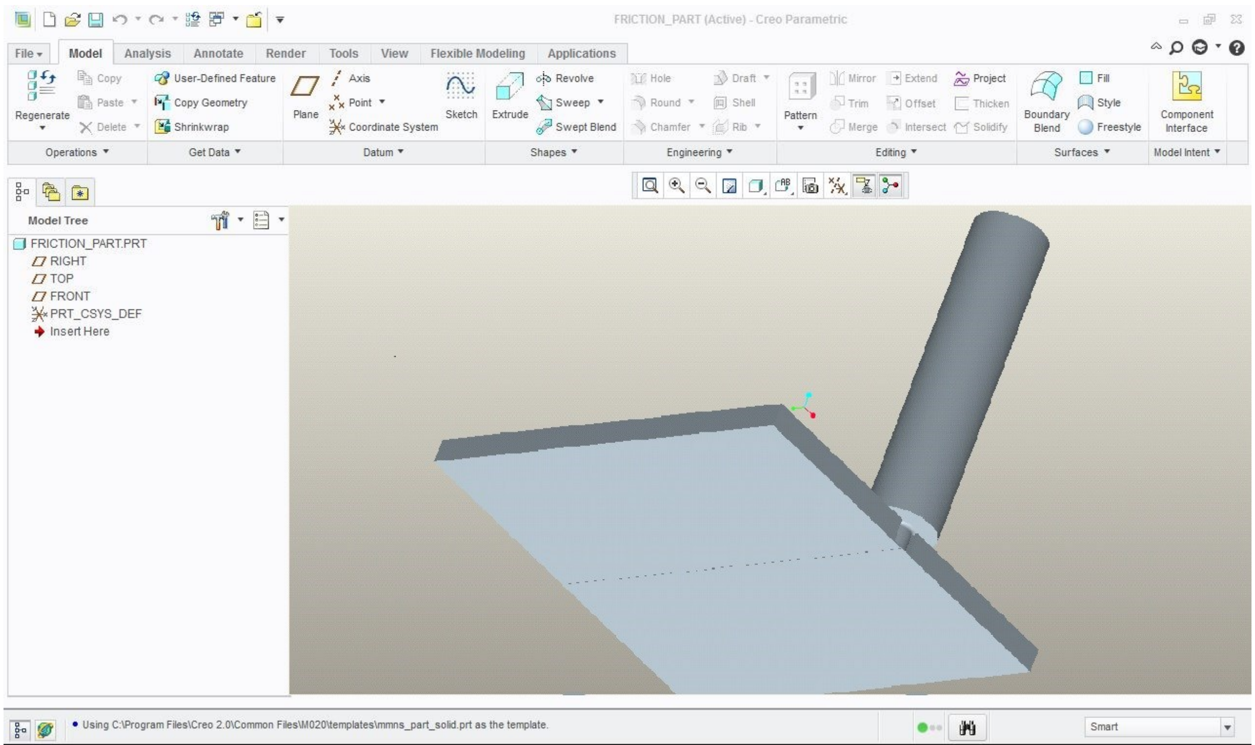


ROUND TOOL



ROUND TOOL ASSM



SQUARE TOOL

PLATE1

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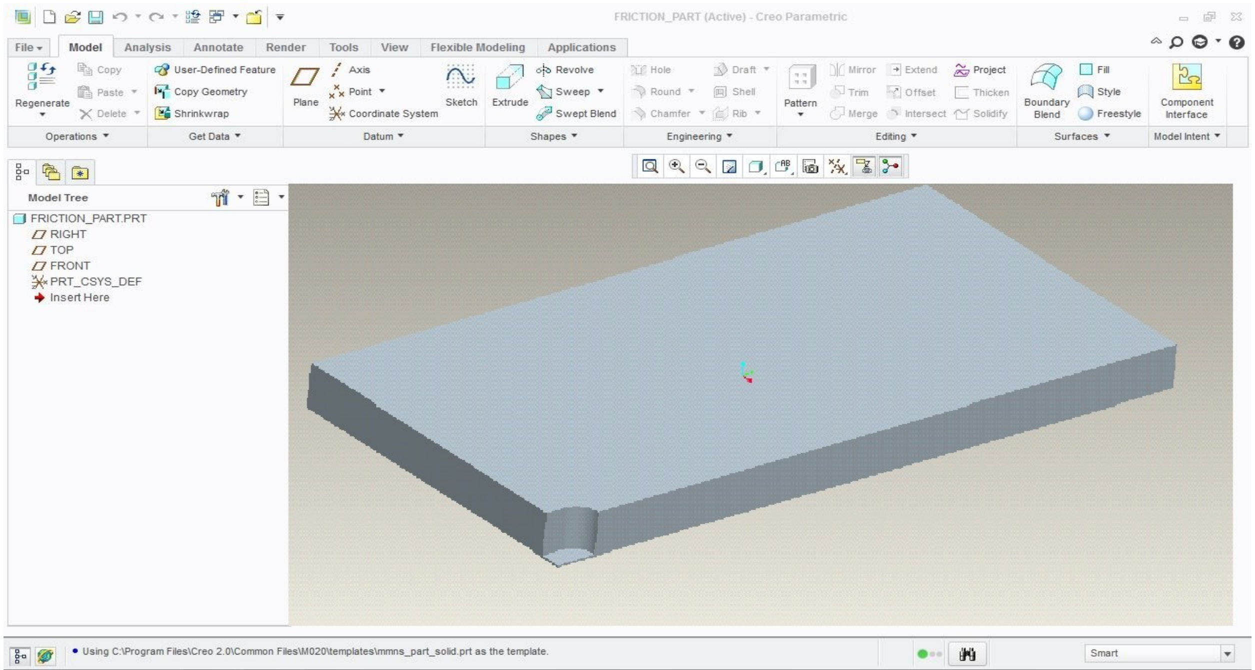
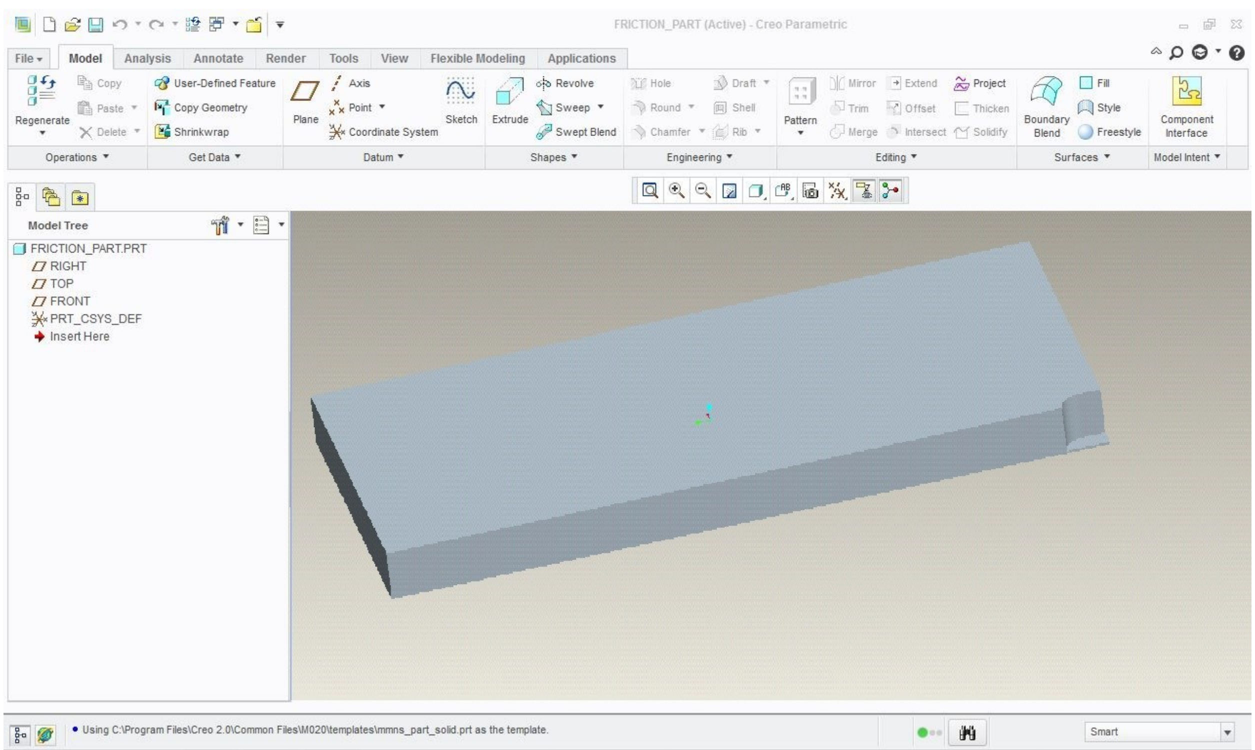
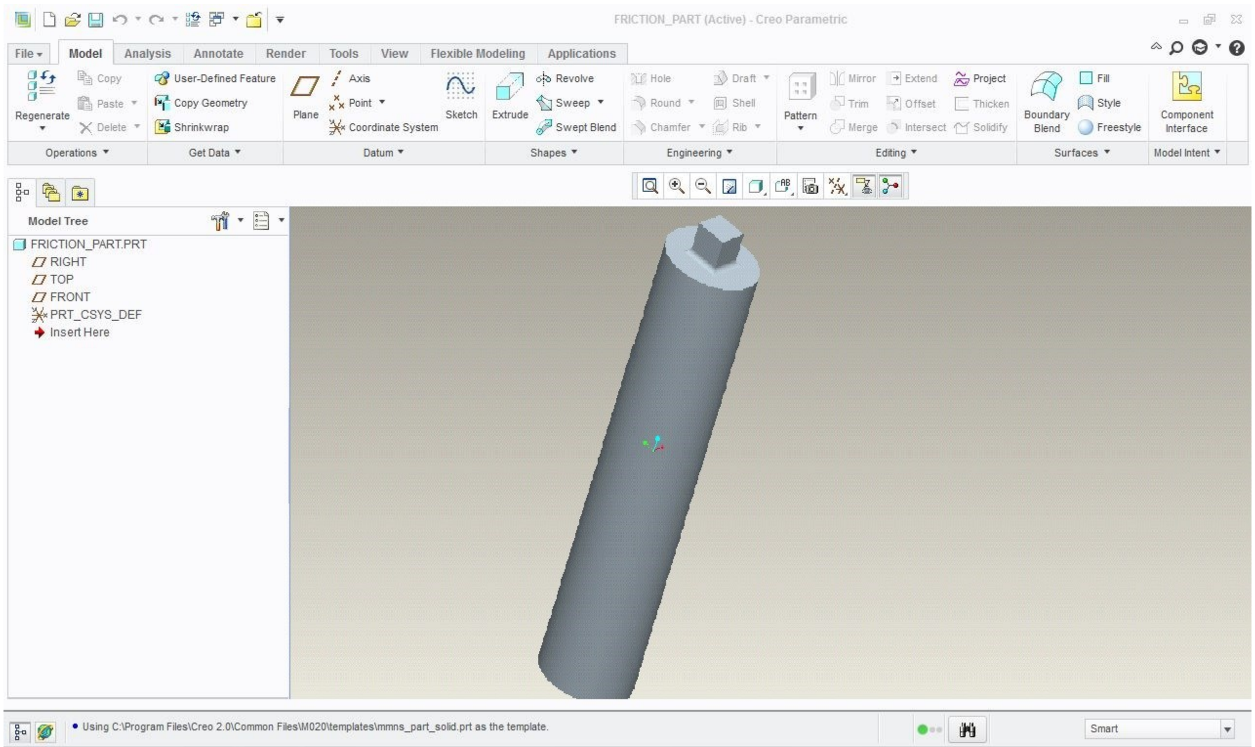


PLATE2



SQUARE TOOL



SQUARE TOOL ASSMEMBLY

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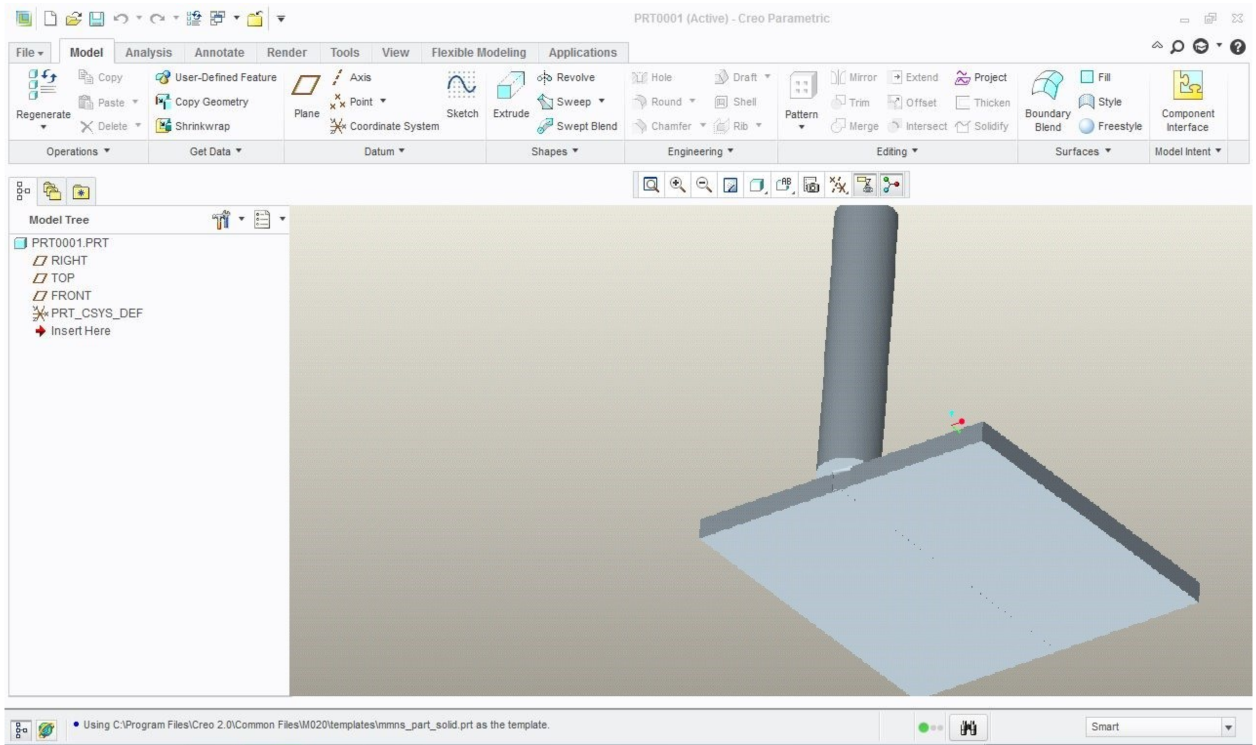

COUPLED FIELD ANALYSIS OF ALUMINUM ALLOY 6061 AND CAST COPPER

1000 rpm

ROUND TOOL

Software used is ANSYS10

Type of analysis done- Couple field analysis

Enter units-/units,si,mm,kg,sec,k

Set working directory

Change job name

Select Preference select thermal

Select element type as a solid brick 20 node 90

Enter material properties as a thermal conductivity 0.18 W/mm. K

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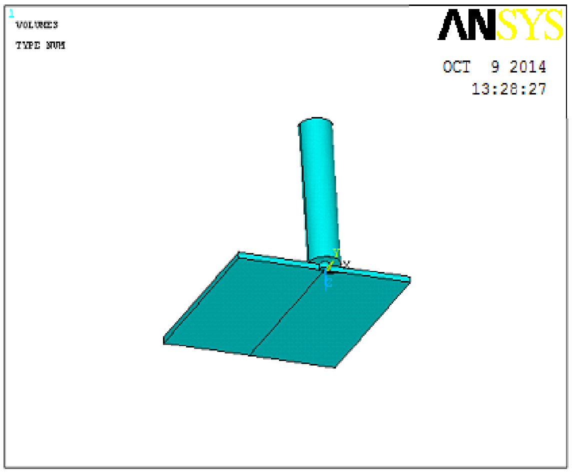
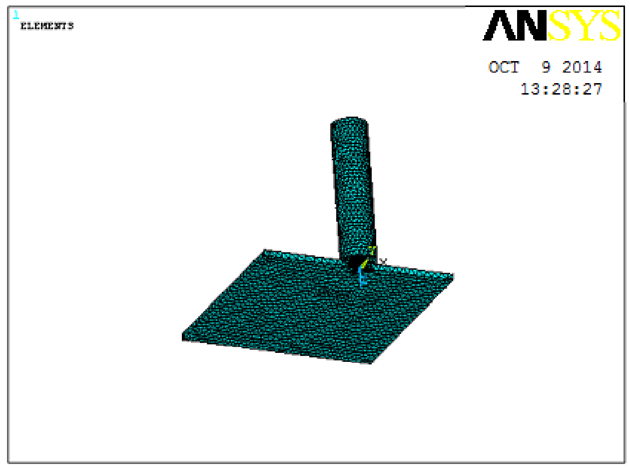
Enter material properties as a specific heat 896 J/Kg-^{0}K

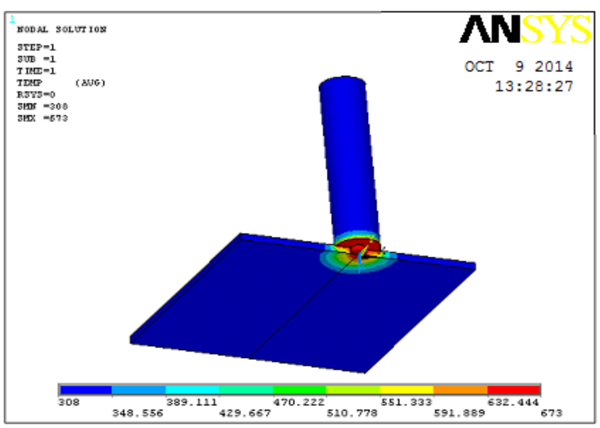
Import IGES model **Meshed model**

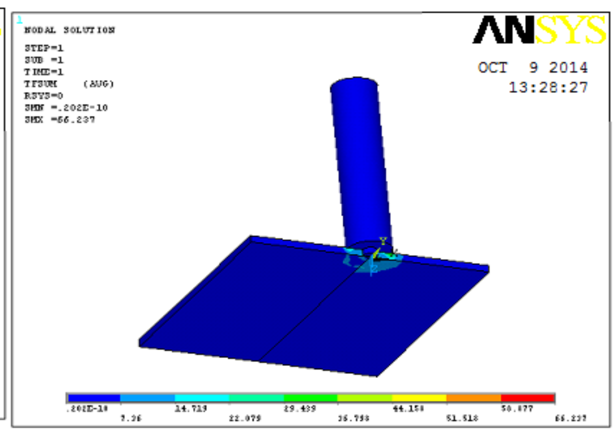




RESULTS OF THERMAL FIELD IN FRICTION SURFACING

Temperature distribution **Thermal flux**





Thermal gradient **Displacement**

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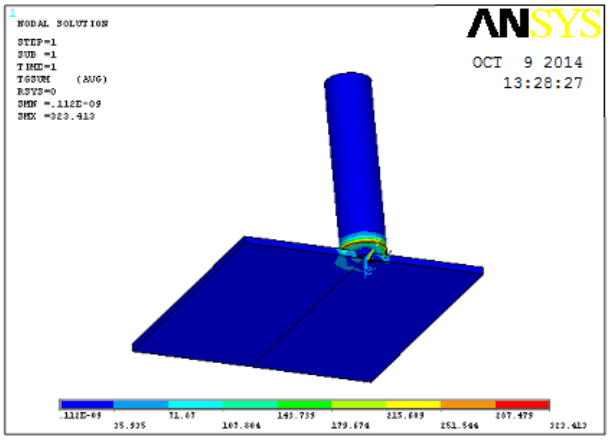
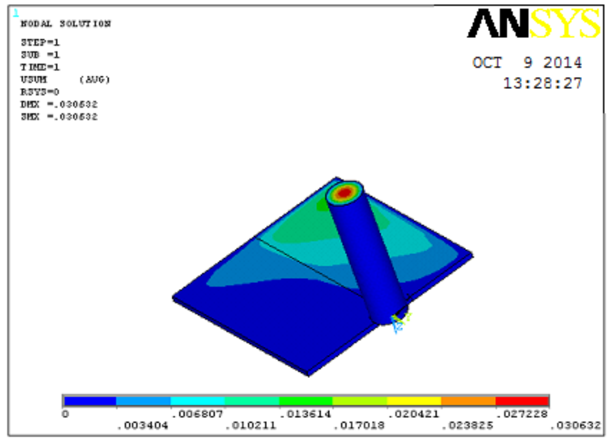
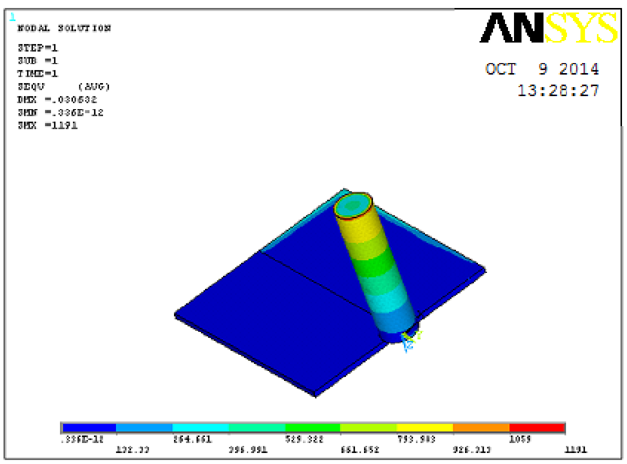
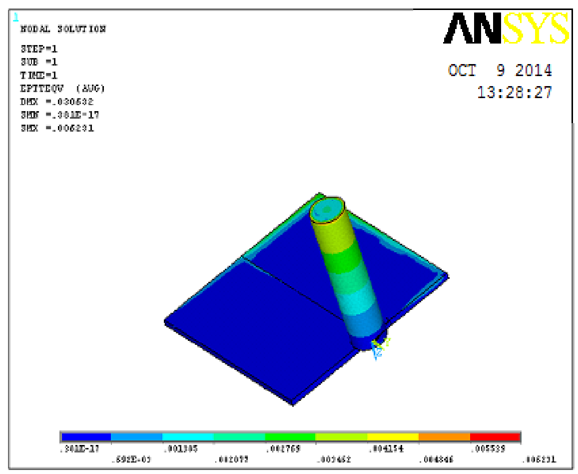




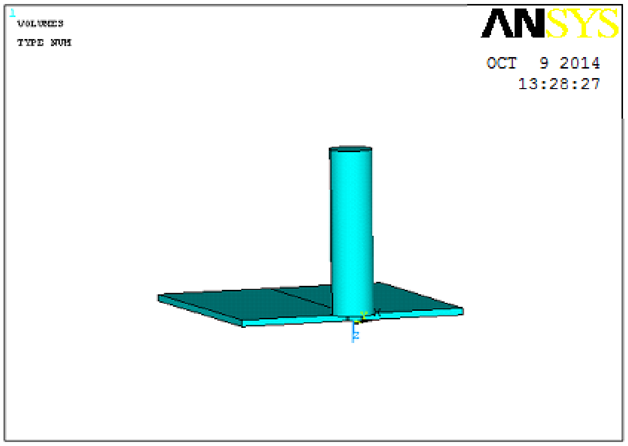
Vonmises stress Strain

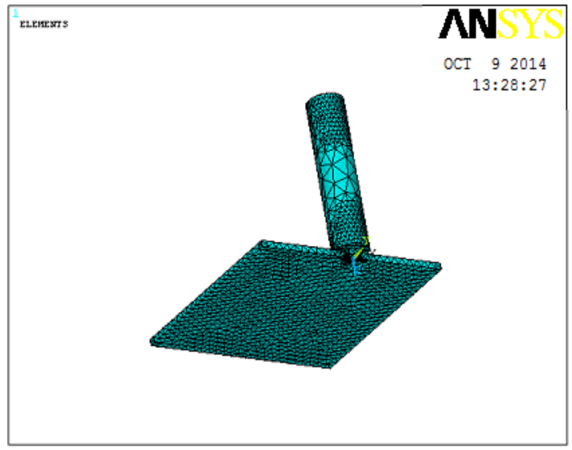




SQUARE TOOL

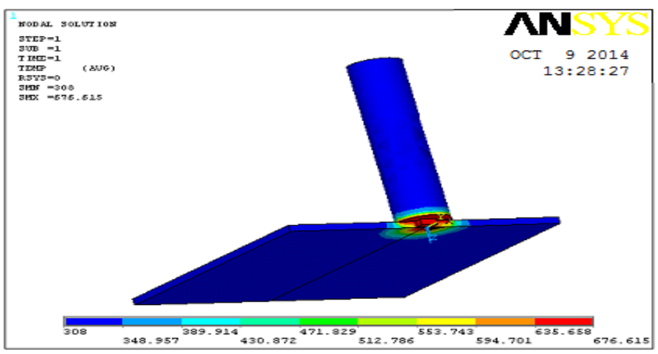
Imported Model Meshed model

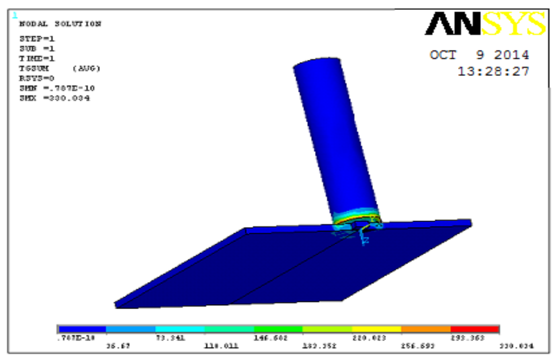




Temperature

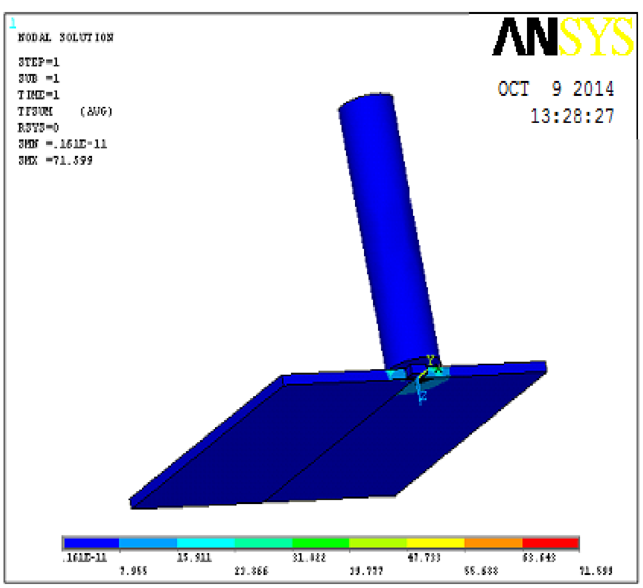
Thermal gradient

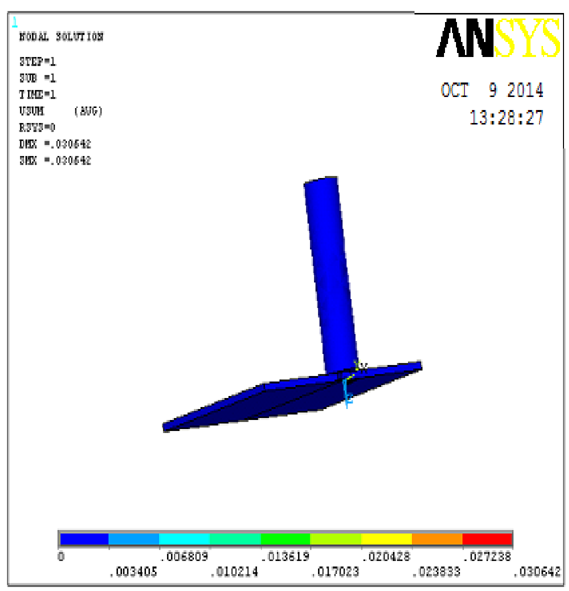




Thermal flux

Displacement





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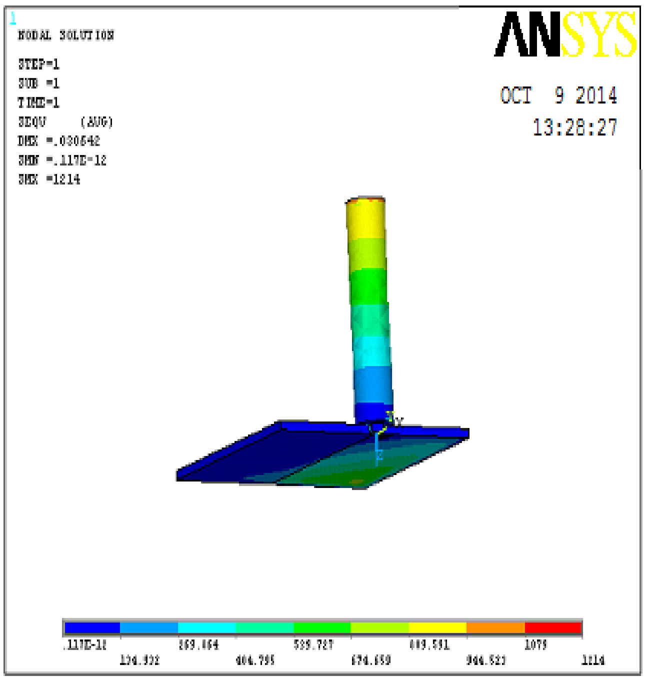
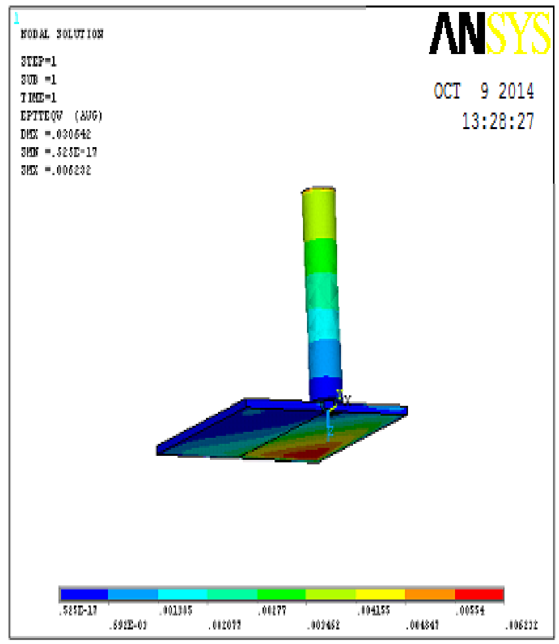
Von misses stress



Strain



STRUCTURAL ANALYSIS OF ALUMINUM ALLOY 6061 AND CAST COPPER

1000 rpm

ROUND TOOL

Imported Model

Meshed Model

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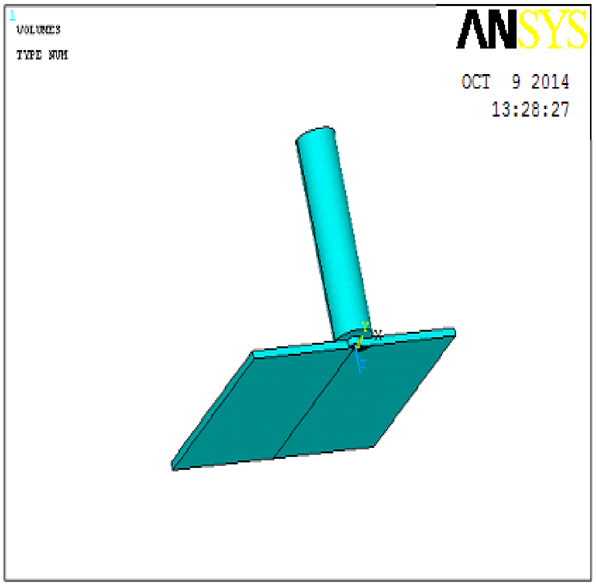
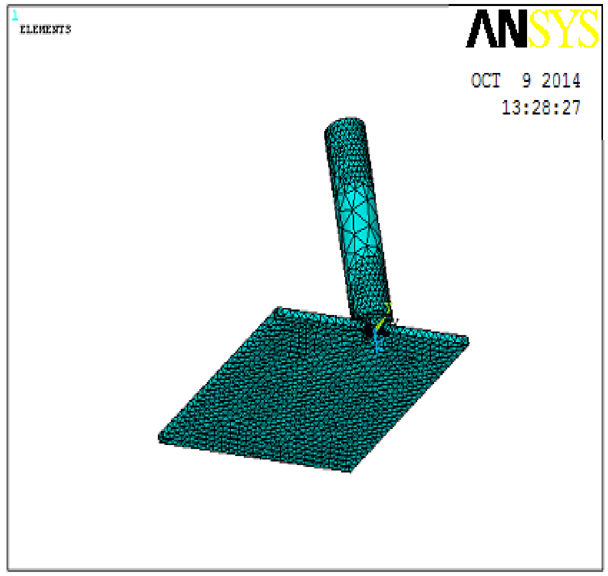
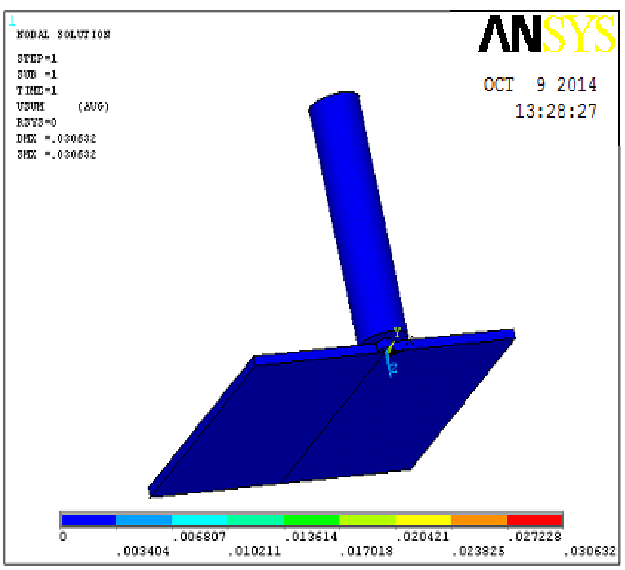
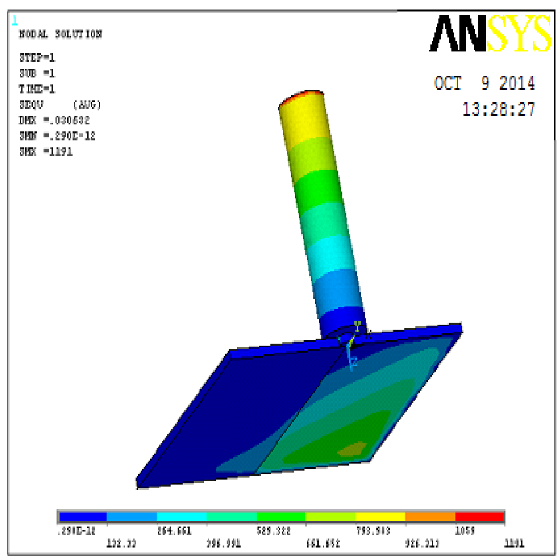
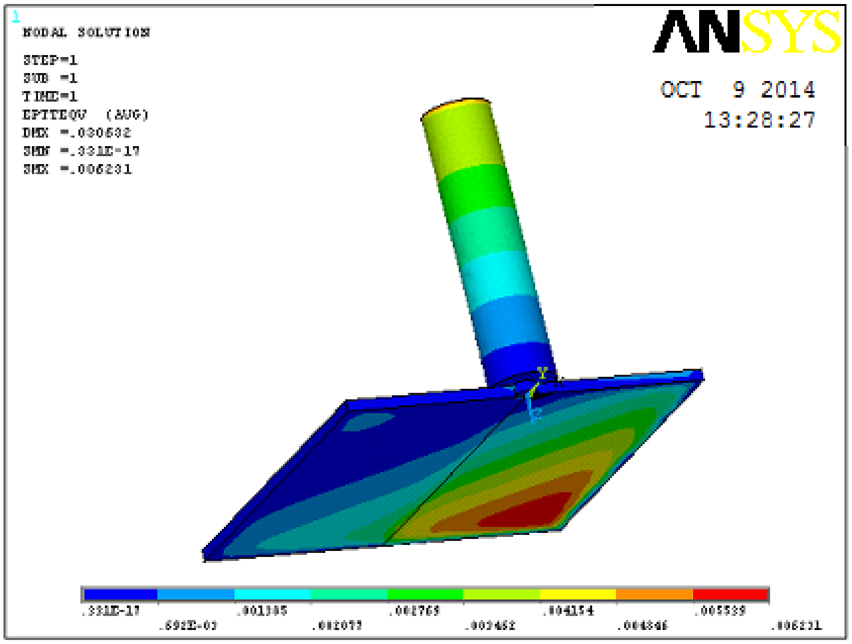




Displacement Stress

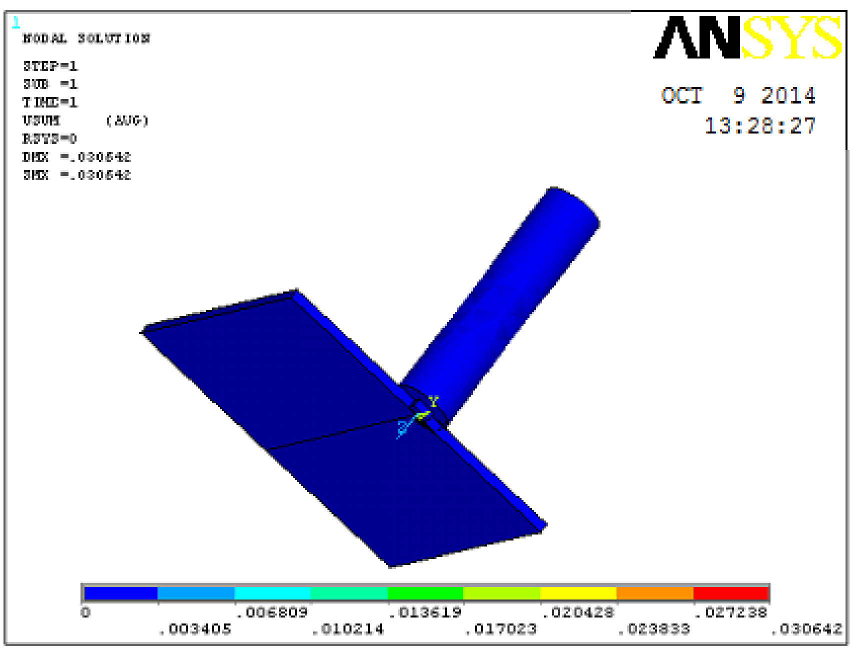






SQUARE TOOL

Displacement



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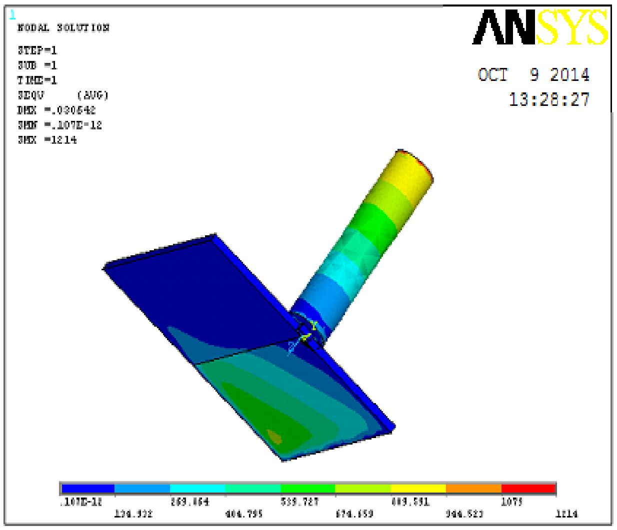
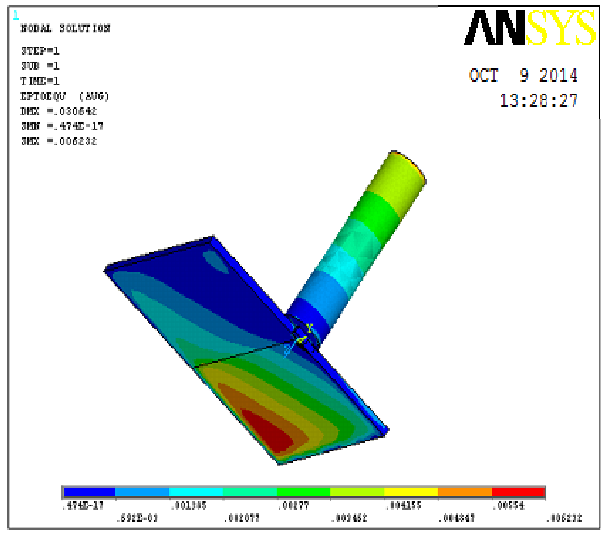
Stress



Strain



ANALYSIS RESULTS SUMMERY

THERMAL RESULT

	Temperature (K)	Thermal Gradient (K/mm)	Thermal Flux (W/mm^2)
Round Tool	673	323.413	66.237
Square Tool	676.615	330.034	71.599

STRUCTURAL ANALYSIS RESULT

	Displacement (mm)	Stress (N/mm^2)	Strain

Round Tool	0.030632	1191	0.006231
Square Tool	0.030642	1214	0.006232

CONCLUSION

In our project we have designed 2 types of cutting tools Round and Square for doing Friction Stir Welding of two dissimilar materials Aluminum alloy 6061 and Copper running at speed of 1000rpm. We have conducted FEA process coupled field and structural analysis on tools Round, Round taper, square, triangle and thread tool to verify the temperature distribution, thermal flux, gradient and stresses. By observing the results, thermal flux and thermal gradient are more for square tool but the stresses produced are more than round tool. Temperature is also produced for required melting point of plates. So for using Friction Stir Welding, round cutting tool is more effective than square tool from FEA results.

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