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STUDY OF TOOL GEOMETRY ON FRICTION STIR WELDING OF AA 6061 AND AZ61

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ABSTRACT : *Friction Stir Welding Process (FSW) is a solid state welding method developed by The Welding Institute (TWI). This research work involves the friction stir welding of two dissimilar metals namely AA6061 and AZ61. The geometry of the tool in Friction Stir Welding (FSW) plays a principle role in quality of the weld. In this study several FSW tools have been considered for the fabrication of a number of butt joints. The tool geometry names are as follows: (i) Straight threaded tool, (ii) Taper Threaded tool, (iii) Inverse tapered tool, (iv) Concave shaped fluted tool. These geometries are analysed for the identification of sound weld through ANSYS.*

Keywords - *Tool Geometry, Friction stir welding, ANSYS.*

I. INTRODUCTION

A method of solid phase welding, which permits a wide range of parts and geometries to be welded are called Friction Stir Welding (FSW), was invented by W.Thomas and his colleagues at The Welding Institute (TWI), UK, in 1991. Friction stir welding has a wide application potential in ship building, aerospace, automobile and other manufacturing industries. The process proves predominance for welding non-heat treatable or powder metallurgy Aluminum alloys, to which the fusion welding cannot be applied. Thus fundamental studies on the weld mechanism, the relation between microstructure, mechanical properties and process parameters have recently been started. Friction stir welding is a relatively simple process as shown in Fig.1.

A method of solid state joining on a workpiece offers a tool pin of material harder than the base metal's continuous surface which causes relative cyclic movement between the pin and the base metal. The frictional heat is generated as the pin stirs the workpiece so as to create a plasticized region in the metal around the probe, stopping the relative cyclic movement, and allowing the plasticized material to solidify around the probe.

This technique, which we refer to as "friction plunge welding" provides a very simple method of joining a base metal through tool pin. Relative cyclic movement between the tool pin and the base metal generates frictional heat causes the opposed portions to take up a plasticized condition, and allowing the plasticized portions to solidify and join the workpieces together. This technique is referred to "friction stir butt welding" which enables a wide variety of workpieces to be joined using a "non-consumable" pin without the problems of oxidation and the like.

A method for ensuring complete penetration of a friction stir weld using a rotating pin friction stir welding tool comprising chamfering the bottom of the plates to be welded along the faying edges. Placing the plates on a back up plate. Inserting the pin friction stir welding tool into the plates to the depth of the chamfer and translating it along the faying surface to plasticize the material in the plates. The plasticized material will flow into the volume defined by of the chamfer at the bottom of the plates and the back up plate. A visual inspection will show if the weld penetrated fully through the plates if the chamfered volume is filled with material which flowed in while plasticized.

It is pointed to the fact that in FSW of AA1100 with a SS310 tool, friction is the major contributor to heat generation. It was observed that tools having a concave shoulder led to lesser temperature rise. At the same time, conical tool pins exhibited somewhat lesser peak temperature compared to that of a cylindrical pin having a pin diameter the same as the base diameter of conical pins. The calculated peak temperatures were all closer to or more than about 80% of the liquidus temperature of AA1100. Therefore, tool geometry with a concave shoulder and conical pin is preferable for FSW of AA1100 [1].

Different designs of tools are presented by Dr. M. Lakshman Rao et al., . Tri flute design tools are complex when compared to the Trivex designs. The effect of tool speeds on the quality of FSW joints is discussed. The tool geometry for a tapered design is given for commonly welded materials [2].

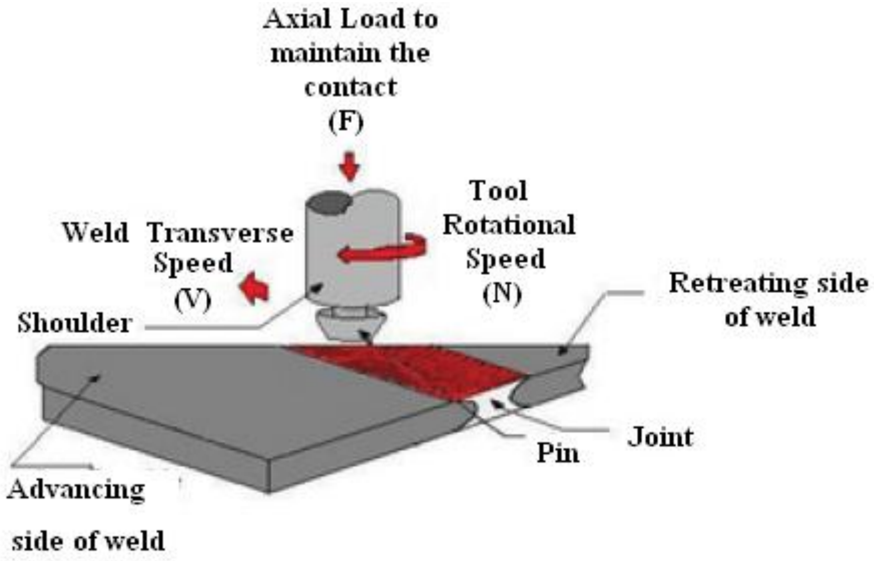


Fig. 1. Schematic diagram of friction stir welding

A sound weld can be obtained using the FSW tool that has a concave shoulder with a diameter approximately equal to four times the welded plate thickness and a tapered cone pin with base diameter equal to the plate thickness [3].

The relationships between tool probe geometry and process parameters for FS welding of AA1100 aluminum alloy have been established. The response surface methodology was adopted to develop the regression models, which were checked for their adequacy using ANOVA test are found to be satisfactory [4].

Optimised tool design can produce welds with 97% of the parent plate tensile strength in this strain hardening 5083-H321 aluminium alloy. The data indicate that the most successful tool designs are likely to incorporate three tapered flutes, a pin diameter taper and have a thread form with a pitch of around 10% of the pin diameter and perhaps 15% of the plate thickness. Further work is required to determine the generality of these conclusions [5].

The scrolled shoulder provides greater grain refinement in the nugget of the welds than the conical or flat shoulders. This refinement is responsible for the increased hardness and mechanical strength of the welds made with this tool [6].

Tools with three different probe lengths were used to join the aluminium sheet with different tool rotational speeds and tool holding times. The weld microstructures varied significantly depending on probe length, tool rotational speed and tool holding time. Two particular aspects were identified: the thickness of the upper sheet under the shoulder indentation and the nugget size. The former decreased with increasing probe length at the shortest tool holding time and the slowest tool rotational speed, but there were no discernible differences in other welding conditions, while the latter increased with increasing probe length, tool rotational speed and tool holding time [7].

Five different tool pin profiles (straight cylindrical, tapered cylindrical, threaded cylindrical, triangular and square) have been used to fabricate the joints at three different welding speeds. Out of the five tool pin profiles used to fabricate the joints, square pin profiled tool produced defect free FSP region, irrespective of welding speeds. Out of the three different welding speeds used to fabricate the joints, the joints fabricated at a welding speed of 0.76mm/s showed superior tensile properties, irrespective of tool pin profiles. Out of the 15 joints, the joint fabricated using square pin profiled tool at a welding speed 0.76mm/s exhibited maximum tensile strength, higher hardness and finer grains in the FSP region [8].

Welds are made to compare the effect of three shoulder profiles: concave, convex and flat (all having threaded cylindrical pins) on the hook geometry and static strength. FSSW-Concave tool yielded higher static strength than FSSW-X and FSSW-F tools at similar plunge depth [9].

The pin design includes a combination of positive threads and flat surfaces. In both embodiments, the positive threads complement the vertical load required to drive the pin into workpieces. The pin diameter is decreased from its proximal end to its distal end, either discretely in steps or linearly in a tapering manner, to further ease penetration of the pin. The decrease in diameter further reduces the amount of transverse welding load required to traverse the pin along the workpieces interface to form an elongate weld [10].

The inventive design results in the Welding tool having a variable effective diameter De. Prior art friction stir Welding tools having a flat shoulder are typically constructed With different fixed shoulder diameters depending on the material thickness, pin diameter, and other factors. However, the tapered shoulder design of the inventive tool can produce a variable effective diameter De simply by changing the depth of penetration of the Welding tool into the workpieces and increasing the depth of penetration of the tool into the Workpieces , will increase the effective diameter De. Similarly, reducing the depth of penetration of the tool into the Workpieces, will reduce the effective diameter De. This increase or decrease in the effective diameter De can be done “on the fly” as the Welding tool is translated along the interface [11].

A multi-shouldered friction stir welding tool comprises an exterior threaded solid pin having a diameter and a length; a shoulder having a threadless inner diameter slightly larger than the diameter of the exterior threaded solid pin and at least one substantially radial threaded set screw hole; an monolithic shoulder-shank having a threadless inner diameter slightly larger than the diameter of the exterior threaded solid pin and at least one substantially radial threaded set screw hole; a pair of locking nuts having a threadless outer diameter and a threaded inner diameter operably compatable with the exterior threaded solid pin, wherein the shoulder and the monolithic shoulder-shank are capable of slidable engagement with the exterior threaded solid pin along the length of the exterior threaded solid pin to set a space slightly larger than a thickness of a workpiece to be welded [12].

$$\frac{T_{max}}{T_s} = (0.0013 - 16.5 \propto)(E_l)_{eff} + 0.56$$

(1)

Utilizing the empirical relationship in Equation 1, the maximum temperature for each SSA038-T6 weld condition can be predicted.

Table 1. Effective Total Energies and Maximum Weld Temperatures for Each Weld Condition

Rev / min	(El) eff (J/mm)	Maximum Welding Temperature (0C)	
		Experimental	Predicted
225	938	346	363
250	977	350	371
300	1331	372	442

400	1567	390	490

Table 1 summarizes these predicted temperatures and the experimental temperatures recorded for each weld trial. At a rotational speed of 225 rev/min, the characteristic curve predicts a maximum temperature of 363°C, a 5% error with respect to the experimental value. A similar success is seen at 250 rev/min for which characteristic curve predicts a maximum temperature of 371°C, only a 6% error [13]. The accuracy of these lower energy results compare favorably with the accuracy of the models proposed by Roy et al. [14] and Colegrove et al.[15].

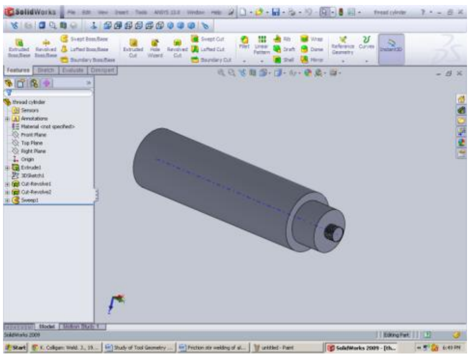
According to the literature survey, it is decided to choose concave shape tool for the current research work which will yield more strength. Two tool profiles (i) concave with star slot and (ii) internal taper pin profile are designed as a new tool model for the welding of AA6061-AZ61.

These chosen tool geometry is compared with two earlier used tool geometries (i) Straight threaded pin and (ii) taper threaded pin.

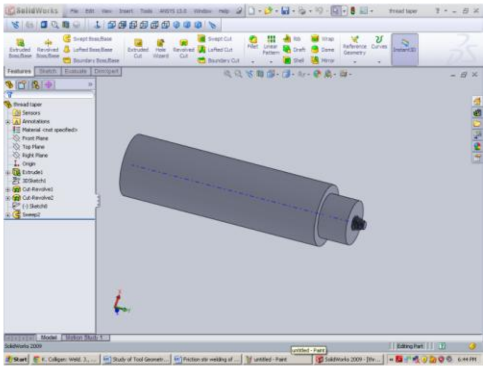
Apart from fusion type welding, the friction stir welding develops heat by the process of joining the metals itself. So a detailed study of tool geometry based on steady state temperature will reveal a good tool geometry. The modeling is made by the modeling software “Solidworks” for the four different tool geometries: (i) Straight threaded pin, (ii) taper threaded pin,(iii) concave with star slot and (iv) internal taper pin profile.

Whenever a force is applied to a mechanical system, it will typically reach to a steady state after going through some transient behavior. This is often observed in vibrating systems, such as a clock pendulum, but can happen with any type of stable or semi-stable dynamic system. The length of the transient state will depend on the initial conditions of the system. So in case of friction stir welding the tool will be getting transient motion and then will reach a steady state. While welding the plates it is having transient conditions, but after relieving from the base metal it will experience a steady state temperature. The present study is focuses on the steady state thermal analysis.

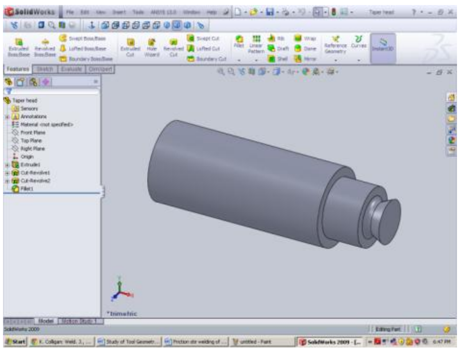
II. RESULT AND DISCUSSION



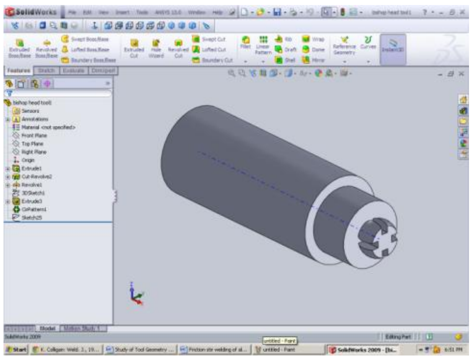
(i) straight threaded geometry



(ii) taper threaded geometry



(iii) The internal taper geometry



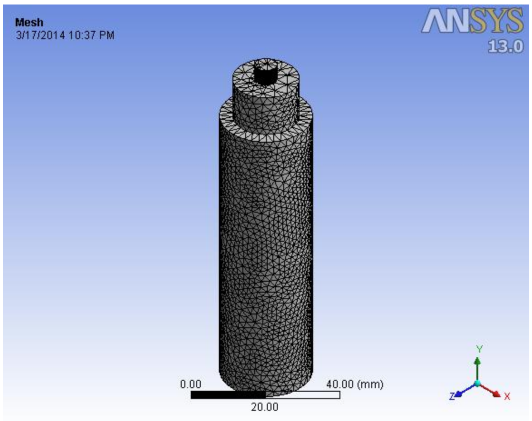
(iv) Concave shaped fluted geometry

Fig. 2. Various tool geometries modeled in Solid works

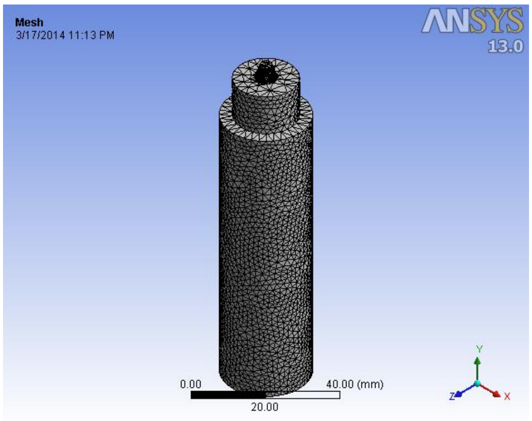
In ANSYS analysis, thermal analysis for steady state is formed with uniform initial temperature of 22^0 C.According to literture survey, temperature varies up to 400^0 C. So Temperature on pin end surface is assumed as 200^0 C and the temperature at shoulder is chosen as 400^0 C. For all geometries element size is taken as 2 mm. The mesh formation for the different tool geometries are shown in Figure 2. Statistics of Finite Element Analysis are as follows:

i. For the straight threaded tool, total number of elements - 15901, total number of nodes-27979.
ii. For taper threaded tool, total number of elements - 16377, total number of nodes-28791.
iii. For internal taper tool, total number of elements - 6938, total number of nodes-12282.
iv. For Concave shaped fluted tool, total number of elements - 6907, total number of nodes-12280.

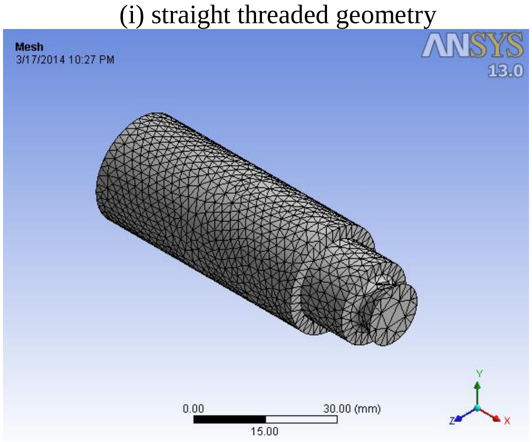
While making analysis, for threaded geometry it is required to make face meshing on threaded parts. These meshing will makes the number of elements and nodes quite higher than internal taper model and concave model. The meshing are shown in Fig.3.



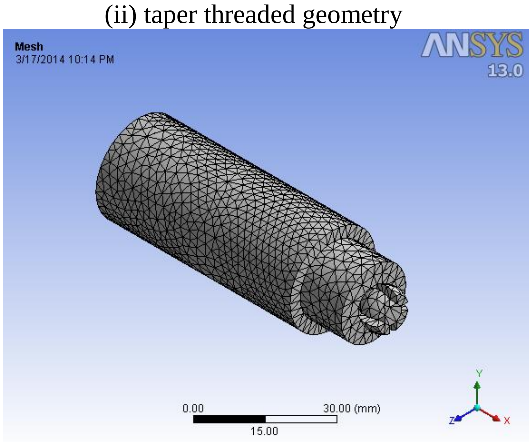
(i) straight threaded geometry



(ii) taper threaded geometry



(iii) The internal taper geometry



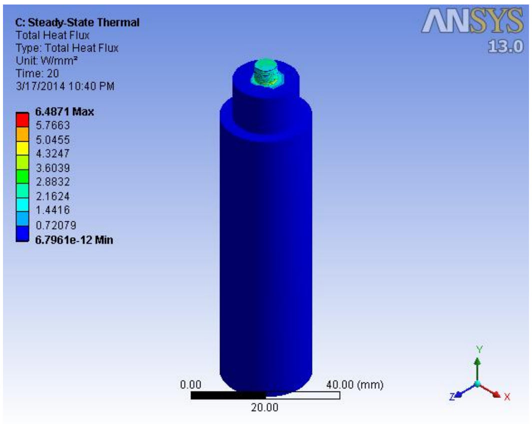
(iv) Concave shaped fluted geometry

Fig. 3. Mesh formation with element size of 2 mm for different tool geometry

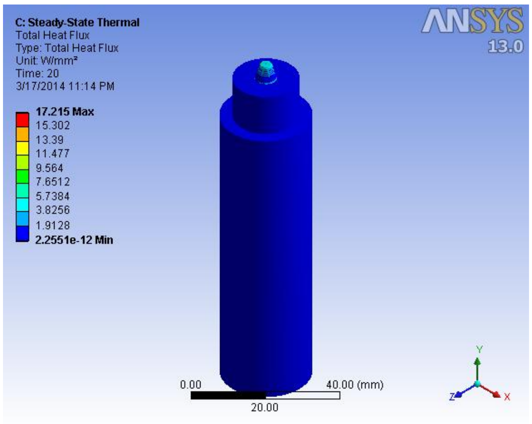
The results of steady state thermal analysis for the four different tool geometry (Fig.4) reveals the following values of total heat flux:

i. The straight threaded geometry gets the max. total heat flux value of 6.4871 W/mm^2.

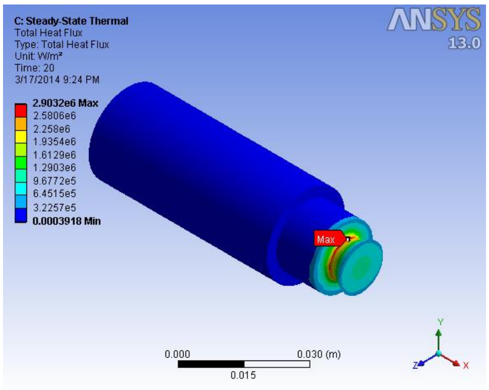
ii. The taper threaded geometry gets the max. total heat flux value of 17.215 W/mm^2.
iii. The internal taper geometry gets the max. total heat flux value of 2.9032 x 10^6 W/mm^2.
iv. The concave shaped fluted geometry gets the max. total heat flux value of 2.9736 W/mm^2.



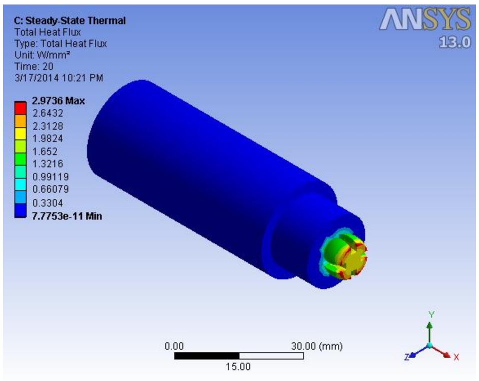
(i) straight threaded geometry



(ii) taper threaded geometry



(iii) The internal taper geometry



(iv) Concave shaped fluted geometry

Fig. 4. Total heat flux with steady state thermal analysis for different tool geometry

III. CONCLUSION

Tool for friction stir welding affects the weld quality of weld. The good tool for making a good quality welding can be identified by conducting experiments with different weld parameters. But this will be cost as well as time consuming. So the analysis tool will relieve the cost and time constraint. According to ANSYS analysis, the concave fluted tool geometry is getting lesser value of total heat flux (2.9736 W/mm2.) compared to other tool geometry. But Internal taper geometry gets the total heat flux much more greater than threaded tool geometry, since it is having the geometry sloping inward and conducts the heat inward. In the threaded tool geometry the heat flux is not getting uniformly distributed, hence the concave shaped fluted tool geometry can be chosen for welding AA 6061 and AZ61 alloys.

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