Thermal analysis of pentagonal profiled friction stir welding tool using Ansys

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Abstract— In friction stir welding process heat generation in the welding zone is most common due to the friction in between the tool and the weldment. When the heat concentration in the weld zone, then the flow of heat through the tool as well as in the weldment. It is requisite to dissipate the heat in order to weld continuously and to increase the weld distance. It is up to the tool design and tool profiles. By doing the thermal simulation in the tool, the tool temperature distribution and compare the number of tools with respect to temperature and able to finalize the tool which has maximum heat dissipation. In this work, 3 tools are designed in total with a pentagon pin profile with different volumes. Which is modeled in solid works software and converted into the Ansys file, then the material properties to be selected, each tool has different materials. Then it gives the corresponding mesh size and boundary conditions such as Temperature, Convection, etc. The tool has been mesh and found out the solution for all tools. As a result, it is found that tool number 1 has a maximum heat dissipation.

Keywords—FSW, Tool, Pentagon, Temperature, Heat dissipation, Convection, Ansys.

1 INTRODUCTION

Friction stir welding is a solid-state welding process that was invented at the Welding Institute in the UK in 1991 december. It seems like a forging process, where the welding is done by the absolute generation of heat. Here the non-consumable rotating tool called friction stir welding tool, which is been used to weld the workpiece. Heat is been generated due to the friction, in addition to this, the component is softened by the FSW tool. When the tool probe touches the workpiece plate, it applies the pressure mechanically like dough. Friction Stir Welding. ‘Friction’ means resistance to the motion, so that heat will be generated. ‘Stir’ is doing the process repeatedly in order to mix. ‘Welding’ is a fabrication process that joins metals or thermoplastics, by using a large amount of heat to melt the parts together and allowing it to cool. The FSW tool is cylindrical in shape with a profiled pin, it usually touches the component while welding. Heat is generated between a rotating tool and the component, where the tool continuously rubs the workpiece for a certain depth. It is used to weld the aluminum and its composites
and also used where it requires high strength. Friction stir welding tool composed of Pin, Shank, and Shoulder. Many different types of tools with different profiles with different materials had been fabricated and tested.

There are different types of pin profiles such as Threaded Cylinder, Plain Tapered Cylinder, and Plain Pentagon. Previously Jayaseelan et.al had studied the paper on the D/d ratio of FSW in aluminum metal matrix composite. In that paper, we had used 3 different tools with different materials. The materials such as oil-hardened normalized steel (OHNS), H13 and HCHCr were used and tested. The material generally plastically deformed because in this process shear force induces in the component. Therefore, there is a gradual increase in temperature. So it is very important to study the mechanical and thermal aspects in friction stir welding. Jayaseelan et.al [2] studied the tool profile and material with respect to the weldment. Also investigated the strength of fsw tool with respect to aluminium metal matrix composite. Sadeesh et.al [5] investigated the welding performance in AA2024 and AA6061. Also they have studied the mechanical properties of the weldment with five different tool designs. They found that welding the base metal below its melting point temperature, welding efficiency will be improved. Jayaseelan et.al [7] carried out welding on Al-SiC weldment by threaded cylinder tool. They studied the influence of tool profile in Al-SiC weldment, material and strength of the weldment. They also did the metallurgical study of the weldment. Koilraj et.al [9] had optimized the process parameters in Friction stir welding of dissimilar aluminum alloys AA2219 to AA5083 using the Taguchi method. Y. N. Zhang et.al [10] summarize the tools in relation to types of tools, Shapes, dimensions, materials, wear behavior, creep, and corrosion resistance. Xue et.al [13] studied the welding effects on the Al-Cu joints. In addition to this, they studied the tool rotation speeds and the pin offset effects on Al-Cu joint. Daneji et.al [16] studied the fsw tool geometry. Also carried out the process parameters and the micrographs of 6061 Aluminium Alloy. Rai et.al [17] done a review paper on fsw aspects of tool design, recent material aspects such as steels and titanium alloys, and its mechanism behind tool degradation, weld quality and its economics. Prabhu Rubesh et.al [18] investigated the study on tensile and wear test of aluminum metal matrix composite. Aluminium, Copper, Magnesium and composite materials were fabricated by stir casting technique. Then its tensile and wear properties were found out. Jayaseelan et.al [20] studied the work of threaded cylinder tools in Al-Br2 composite. In this paper we did the thermal simulation with the help of a software called Ansys workbench. In detail, we did a thermal simulation for the 3 tools and found out the temperature distribution, heat dissipation.

2 EXPERIMENTAL WORK

2.1 Modelling in Solid works

Solid Works is a Solid Computer-aided Design (CAD) software that is widely used to model the components and systems in the 3D model. The software is owned by Dassault systems. In this software we were designed every tool with the help of the commands in solid works. All the tools are cylindrical in shape, hence we had used the circle command in the majority, in a supplement to that other commands like Extrude Boss were used in order to convert the 2d to 3d structure. While considering the pentagon
profile, the actual pentagon command was not there. So we used the polygon command and changed the number of sides to 5, therefore the absolute pentagon surface was created. So after successfully designed all the 3 tools as per the dimension, we cater to save the file in the IGES format. Jayaseelan et al. [4] studied the character of the cylindrical threaded tool with different materials and micrographs of Al-SiC and Al-ZrB2. The micrographs of the weldment and the tensile, hardness values also were studied. Krasnowski et al. [11] have investigated the tool shape and weld configuration on the microstructure and mechanical properties of the Al 6082 alloy FSW joints. Christian Fuller et al. [12] investigated the paper on friction stir welding tools design and effects of welding by various fsw tool design. The materials of the fsw tools and its properties also discussed. L. Shi et al. [15] investigated the L.Fu, Effects of tool shoulder size on the thermal process and material flow behaviors in ultrasonic vibration enhanced friction stir welding. Amini et al. [19] carried out the work on friction stir welding tool geometry on of 5083-O aluminum alloy. So that we can import the file into ansys directly. The fig 2.1 shows the diagrammatic representation of Friction stir welding tool.

![Solid works model of FSW tool with Pentagon Pin Profile](image.png)

**Fig. 2.1 Solid works model of FSW tool with Pentagon Pin Profile**

### 2.2 File conversion into Ansys

Ansys is a finite element analysis software, which was founded by John Swanson in the year 1970. Which is used to simulate engineering problems. We can simulate and obtain the solution for problems like Structural, Thermal etc. In general, ansys software analyze the component by creating the mesh. i.e.) dividing the component into finite surface area and find the solution. Here greater the fine surface, greater the accuracy. We can find the solution on the basis of Strength, Toughness, Elasticity, Thermal distribution such as Temperature, Fluid flow etc. Here we convert the file from solid works to ansys. In the home page, we have to select geometry>import> browse. Then the select the file which we already saved in the form of IGES format. So the component will be generated in the ansys display. Hong-yang et al. [3] modelled the intake water tower from solid works and converted into the ansys file. Then found out the solution on Thermal stress and Thermal strain.
After the generation of the component, we gave the material data by selecting the engineering data in the home page. Hence all the 9 tools are belonged to the steel family. But in particular, we couldn’t able to find the material (OHNS, HCHCr, and H13 steel). So by default it would shows the structural steel. We have an option to change the Young’s modulus, elasticity, poison ratio. So that we can obtain the required material. Then we have to select the model in order to give the thermal loads and find the result. So firstly in this transient ansys, we have to give the mesh size. For the mesh size, we have followed the theory called grid Refinement Theory. There is an option called refinement in ansys workbench. It used to fine the mesh size manually. But we had followed the actual finite element theory to find the correct mesh size. Which means we have to give the least mesh size. In sometimes, if we give the size of 1mm which may considered as the least size. But system cannot process the solution in the mesh size of 1mm. For that we need to find the correct mesh size by increase the mesh size until the system finds solution. For instance, initially I gave the size of 1mm but system didn’t process the solution. Hence I increased the size up to 1.4 mm. So in the mesh size of 1.4mm, system was able to process the solution. More importantly, I’m not supposed to give the same mesh size for all the 3 tools. Different mesh size may require for each tool. So we found the mesh size for each tool.

Table 1. Mesh size for the corresponding tool

| Tool Number | Mesh Size(mm) |
|-------------|---------------|
| Tool no: 1  | 1.398         |
| Tool no:2   | 1.377         |
| Tool no:3   | 1.395         |

2.3 Thermal Loads

According to the thermal loads, we have given the data as per the data which were recorded during the welding by the assistance of 9 tools. Temperature were recorded with the help of thermocouple at the tool surface. Initially after the conversion of file from solid works to ansys workbench, we cater to give the material properties such as Thermal conductivity, Density etc. Once we enter into the model page, where we gave all the thermal loads such as temperature foe all the step and convection coefficient.

2.3.1 Temperature

Temperature is the most important load in friction stir welding. In general heat is been generated because of friction, it is very requisite to measure the temperature parameters in order to make a thermal simulation. Here while welding itself temperature was been recorded by the temperature sensor. For every tool different temperature was generated, it depends upon tool profile. Initially when the probe touches the work surface it goes into the particular depth. So while going into the certain depth by continuous rotation the heat generated. Since rpm is been constant, but the profile and tool parameters varies. That’s the reason behind measurement of temperature parameters. The work piece is about 100mm in length. Let say if a tool having the maximum temperature
of about 900°C, it would not be generated at initial level itself. It entirely depends upon the time duration and the length. In ansys software, especially it’s a transient analysis so we are supposed to give a temperature parameters with respect to time. We can assume any number of steps and we can give the time according to that. While do the welding operation itself we divided the welding steps into 5. This is because the total time to weld the workpiece is about 10 mins. So divided into 5 steps. Each step lasts for 2 mins. For each step we need to mention the temperature with respect to time. The following table shows the temperature value for each step with respect to temperature.

Table 2. Temperature for the tools at each step

| Tool No. | Initial Temp. °C | Step 1 (2 min) °C | Step 2 (2 min) °C | Step 3 (2 min) °C | Step 4 (2 min) °C | Step 5 (2 min) °C |
|----------|------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| 1        | 30               | 125               | 385               | 524               | 746               | 917               |
| 2        | 30               | 118               | 368               | 565               | 759               | 898               |
| 3        | 30               | 127               | 357               | 551               | 784               | 920               |

2.3.2 Convection

Convection is one of the modes of heat transfer. It transfer the heat by the movement of fluids. In friction stir welding, at the probe surface the heat is been generated. Where the heat travels toward the end by conduction. Generally the end surface is fixed in the chuck. Normally heat travels till the end surface. If the high amount of heat travels through the end surface, which is been hold by the chuck, the machine will gets affected. So the heat flow throughout the tool should be dissipated. In supplement to this effects, one more adverse effect of high heat generation is the pin surface will be damaged or even in sometimes it gets broken. So it is very necessary to study about the heat distribution rate and heat dissipation rate. That is the motivation of this study. In case of the heat generation the heat would be generated at the pin surface and might be till the shank. In contrast to that, all other surface will be exposed to convection. Since the tool is rotating at 1000 rpm, so probably convection played crucial role in heat dissipation in all the 9 tools. In ansys workbench when we are giving the thermal loads we are supposed to give the convection heat transfer coefficient in order to give the boundary condition for the system to find out the temperature distribution rate and other required solution. Here the convective heat transfer is done by air. Normally air has the convective heat transfer coefficient of about 5-10 W/m k. Here we taken the convective heat transfer coefficient of 10 W/m k.

2.4 Simulation process in Ansys

After starting the Ansys 18.1, we should click on the option called Transient thermal in home screen which is situated in the analysis systems in the tool box. Then the process bar will be displayed. Initially we have to give the material parameters in the engineering data. In this we paper we had used 9 tools in total and 3 materials. Hence we have to give the data such as Thermal Conductivity, Density and Specific heat.
[1]. Had studied the thermal simulation in fsw in the workpiece. They found the temperature distribution in the component during the operation. Heidarzadeh et.al [6] have studied the tensile properties of AA6061-T4 composite. The following table shows the material properties for 3 materials which was actually been used in the experiment.

\[
\begin{array}{|c|c|c|}
\hline
\text{Tool material} & \text{Thermal Conductivity (W/mk)} & \text{Density (Kg/m}^3\text{)} \\
\hline
\text{OHNS} & 31.1 & 8670 \\
\text{HCHCr} & 24.2 & 7890 \\
\text{H13} & 24.7 & 7890 \\
\hline
\end{array}
\]

Gaoqiang Chena et.al [14] analyzed the Thermo-Mechanical properties of friction stir welding tool with a retractable pin profile. Sheikhi et.al [8] investigated the microstructure and mechanical properties of dissimilar friction stir welds in aircraft aluminium alloys 2024-T351 and 6056-T4. Once we gave all the material properties the system would set the properties for the tools. By selecting the back to project on the top we will back to the home screen. Then in the geometry, just by right click and select the import geometry I can able to import the geometry in the ansys workbench from solid works. After that, there is section called model where we gave all the boundary conditions. In the model option by gave a double click, the definite model of the component would be loaded. Hence by opening the model, we can view the tool model. Initially we have to give the mesh size as per the table which we mentioned above. Here the mesh should applied for the entire tool body. By selecting the body we gave a mesh and we cater to select the generate mesh. So that our entire tool was meshed. After the mesh, we need to give the analysis conditions. Where we should divide the steps into 5. Because the tool was completed the one pass by 10 mins at a speed of 50mm/rev. Hence we divided the steps into 5. Each steps possess for 2mins. In addition to this we cater to mention the temperature for each step. Because at each step different amount of temperature was generated. Then after we gave the important boundary condition such as temperature, convection. It is very important to select the proper selection for temperature, convection and heat flux. Our final result absolutely depends upon the selection of sections.

3. Results and Discussion

Hence all the 3 tools were simulated successfully and it was found that tool number 1 has maximum amount of heat dissipation. The total volume of the tool number 1 was well suited for friction stir welding. Here D/d ratio plays the vital role in dissipation of heat. While rotating initially, it generates more heat than tool number 2. But the tool volume dissipate more heat than other 2 tool. By analyzing the results and the images which are attached below, we can see that tool no 3 has the highest heat distribution than other tools. Also it was very good during welding and has the excellent micro graphical properties. All the temperature distribution values are equal with the data with the data which were recorded during the experiment by thermocouple. The following images shows the temperature distribution in the tools.
Fig 3.1 Temperature distribution for tool number 1

Fig 3.2 Temperature distribution for tool number 2
Fig 3.3 Temperature distribution for tool number 3

The following graphs shows the temperature distribution at various surfaces at the tool. The graph was plot by Temperature vs Tool

Fig 3.4 Temperature history at pin surface
Fig 3.5 Temperature history at Shoulder surface

Fig 3.6 Temperature history at balancing weight surface
Fig 3.7 Temperature history at Shank surface

4. Conclusion

In comparison of thermal distribution of overall 3 tools, it concludes that tool number 1 has the maximum heat dissipation

- In spite of good heat dissipation, we can weld more than 100 mm with the tool number 1
- During welding, the work by tool number 1, it has less number of friction. So it can able to stir freely and easily. As a result less number of heat was flow through the tool
- The volume of the tool 11 was very good for friction stir welding. Heat dissipation was much better than others
- Mechanical and Metallurgical properties of tool number 1 with respect to the work was excellent than others.

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