STUDY OF INFLUENCE OF TOOL GEOMETRY ON MATERIAL FLOW PATTERN IN FRICTION STIR WELDING PROCESS USING FINITE ELEMENT SIMULATION

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ABSTRACT

Material flow pattern studies are conducted during the friction stir welding process, to evaluate the influence of tool geometry on the flow characteristics. This is done considering the material movement in the case of friction stir welding is happening by material flow around the rotating tool and is considered as a viscous flow exhibiting laminar flow characteristics exhibiting non-Newtonian properties. Velocity field and the viscosity fields are considered as the criteria to differentiate the various weld zone viz. Weld nugget zone, HAZ & TMAZ. To compare the influence of tool geometry on the material flow behavior various tool pin profiles are considered and the resulting velocity distributions are compared. The results obtained revealed the tool pin geometry has a considerable effect on the weld nugget zone.

KEYWORDS: Friction Stir Welding, Material Flow, Fem, Velocity field & Tool Geometry

INTRODUCTION

Friction Stir welding process has been a significant metal joining process since its invention by The Welding Institute(TWI) in 1991[1]. Friction Stir welding process is a joining process which employs a tool which rotates and travels along the joining surfaces which are clamped together. The tool is non-consumable and many types of tool profiles are employed for the welding purpose. Tool geometry is defined by the diameter of the shoulder, diameter of the pin, shape of the pin and the pin length. The pin length is usually shorter than then the thickness of the plates to be welded. The pin is penetrated into the work pieces and the tool rotates and transverses along the centerline. The interaction between the work piece and the tool results in friction generating heat which in turn creates plastic deformation and the flow of the work piece material takes place in plasticized state as the tool traverses forward [2]. The process is illustrated in the Figure 1.

The material flow in friction stir welding is complex in nature and mainly depends on the tool geometry, process parameters such as tool rotation speed, welding speed, tool tilt angle, axial force and properties of the material to be welded. The weld formation depends on the material flow behaviour of the materials, to be welded.
As friction stir welding is a fusion welding process the welding takes place due to the intermixing of the materials for which material flow is the primary criteria which happens in solid state due to the heat generated due to friction between tool and work piece. Earlier researchers showed that the feasible way to join steel and aluminum is by Friction Stir Welding (FSW) [3]. They were able to join 2 mm thick plates and have obtained a joint tensile strength about 86% of that of Al base metal [4]. It was also demonstrated how to join Al 6061 and mild steel plates having 6-mm thickness by some researchers [5]. A steel/Al weld having higher average joining strength and hardness value than base Al was obtained [6]. Intermetallic Compounds at the interface and blocky steel particles were observed in the weld. Six different phases were identified in the binary phase diagram of Fe-Al system [7] and formation of large amounts of intermetallics will drastically degrade the mechanical properties (tensile strength, etc) [8]. Complete interface micro structural analysis has been reported on the welds [9]. Various sizes of steel fragments were found in the entire region of nugget (weld) zone [10]. Recently, researchers reported a detailed analysis of how IMC layer of distinct thickness and composition can be obtained which influenced the mechanical properties of dissimilar joints of 2 mm steel and Al alloys [11]. Earlier researchers showed the processes feasible for joining aluminium to steel [12-13]

**MATERIALS & METHODOLOGY**

**Experimentation**

In this study 8mm sheets of AA 6061 are welded to 8mm The chemical of the material composition and tool description are tabulated in the Table 1 and Table 2.

<table>
<thead>
<tr>
<th>Tool Number</th>
<th>Tool Profile</th>
<th>Length of the Pin (mm)</th>
<th>Diameter of the Pin (mm)</th>
<th>Diameter of the Shoulder</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Taper</td>
<td>7.8</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Hexagon</td>
<td>7.8</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>Cylindrical</td>
<td>7.8</td>
<td>4</td>
<td>12</td>
</tr>
</tbody>
</table>

**Table 1: Composition of AA 6061**

<table>
<thead>
<tr>
<th>Element</th>
<th>Al</th>
<th>Mg</th>
<th>Si</th>
<th>Cu</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount (wt %)</td>
<td>Bal.</td>
<td>1.0</td>
<td>0.6</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>
The friction stir welding process is carried on a modified vertical milling machine on which a specially designed fixture is mounted to hold the 100mmX200mmX8mm plates and clamped firmly. Experiments are conducted using tools of varying tool pin profiles to estimate the impact of the tool pin profile on the weld strength. Taper, hexagonal and cylindrical tool profiles are used for the welding purpose and comparison of the mechanical and macrostructures properties is done. The process parameters for tool profiles are kept constant as follows the tool rotational speed of 1400rpm and welding speed of 60mm/min. Temperatures are measured using K-type thermocouples during the welding process to estimate the heat generated during the friction stir welding process using different profiles.

**Process Modeling**

Eulerian flow formulation is adapted in the process modeling of friction stir welding, with the following assumptions:

- As we are considering aluminum as the material the elastic behavior and strain hardening are neglected to keep in view the high strains expected in the case of aluminum alloys during FSW.
- The fluid flow that occurs during the FSW process is attributed to the pure plastic deformation without strain hardening.
- Flow stress of the material is modeling using Zener-Hollomon equation.
- Fluid flow is considered as laminar this is due to the high temperatures which are generated near the pin resulting in high rates and viscosity due to which calculated Reynolds numbers are very small.
- The 3-dimensional material flow that happens during the FSW process is modeled mathematically as a steady-state laminar flow happening around the rotating pin considering the fluid as an incompressible and non-Newtonian and the material is flowing through a stationary discretized flow zone, a stationary mesh instead of moving mesh is considered.
- The heat generated is attributed to the viscous dissipation inside the fluid.
- In this study, a validated model of the FSW process was generated using the CFD software FLUENT, with this model then being used to assess in detail the differences in flow behaviour, mechanically affected zone (MAZ) size and strain rate distribution around the tool for various tool geometries.
RESULTS AND DISCUSSIONS

To determine the flow behavior of the material with change in tool geometry without altering other process parameters as mentioned above. figure 3a, 3b, 3c show the meshing model of various tool geometries viz. cylindrical, hexagonal and tapered tools. Similar boundary conditions are chosen for all the simulations and various contours are plotted to observe the difference in patterns.

Figure 3(a): Meshing Model of Cylindrical Tool

Figure 3(b): Meshing Model of Hexagonal Tool

Figure 3(c): Meshing Model of Taper Tool

Figure 4a, 4b & 4c show stream lines which are different for different tool geometries. Uniform stream lines are observed for the hexagonal which is attributed to the symmetrical edges which force the material around the tool uniformly

Figure 4(a): Material flow with Cylindrical Tool

Figure 4(b): Material Flow with Hexagonal Tool
Figure 4(c): Material Flow with Taper Tool

Figure 5a, 5b & 5c show velocity contours of the FSW process with different tool profiles. Higher velocities are observed around the hexagonal tool compared with cylindrical and tapered tools. Very low velocities are observed around the tapered tool. Velocities around the hexagonal tool are high and uniform.

Figure 5 (a): Velocity Contour of Cylindrical Tool

Figure.5(b): Velocity Contour of Hexagonal Tool

Figure 5(c): Velocity Contour of Tapered Tool

Figure 6a, 6b & 6c show pressure contours around the tool during the FSW process. It is observed the pressure is maximum on the advancing side for all the tools and the pressure on the retreating side is low for hexagonal tool.

Figure 6(a): Pressure Contour of Cylindrical Tool
Figure 6(b): Pressure Contour of Cylindrical Tool

Figure 6(c): Pressure Contour of Tapered Tool

Figure 7a, 7b & 7c show the Turbulence contour for the FSW process with different tool. It is observed that for Tapered and cylindrical tools higher turbulence are noticed away from the tools which is undesirable and in the case of Hexagonal tool the turbulence contour yielded good results.

Figure 7(a): Turbulence Contour of Cylindrical Tool

Figure 7(b): Turbulence Contour of Hexagonal Tool

Figure 7(c): Turbulence Contour of Tapered Tool
Micro structural studies are conducted for correlating the results with the simulation results. Figure 8 a,8b,& 8c show the Macrostructure of the FSW weld zone obtained with Hexagonal tool, Microstructure of the FSW weld zone obtained with Hexagonal tool and Grain size distribution according to plain metric method of the FSW weld zone obtained with Hexagonal tool.

Metallurgical suggest the hexagonal tool yields good results and the grain structure and grain size distribution results suggest that the very fine grain size with uniform distribution is found in the nugget region which is a result of uniform distribution of the material in the weld zone which correlates with the simulation results.

Figure 8(a): Macrostructure of the FSW Weld Zone Obtained With Hexagonal Tool

Figure 8(b): Microstructure of the FSW weld zone obtained with Hexagonal Tool

Figure 8(c): Grain size Distribution according to Plainimetric method of the FSW Weld Zone Obtained with Hexagonal Tool

CONCLUSIONS

The study shows that there are significant differences in the flow behavior, around and under the tool when the tool geometry is changed and it shows that the proposed approach is able to predict flow around the FSW tool. Good correlation is found between the simulation results and the experimental results and hexagonal tool yields good results compared with cylindrical and tapered tools.

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