Effect of tool geometry and its parameters of friction stir welding on aluminum alloys: A review

Vadapalli Preetham Kumar[1], Dr. Y Seethamrama Rao[2]
[1]*M. Tech Student, Department of Mechanical Engineering, GVP College of Engineering and Technology*
[2]*Associate Professor, Department of Mechanical Engineering, GVP College of Engineering and Technology*

***Abstract*—This paper reviews; the geometry of tool and its parameter's which effect on properties of similar materials weld joint have been studied. Joining similar alloys AA5082 is used in automotive components, transmission towers, structural or architectural, frames and scaffoldings because of its characteristics. For the joining of low melting point materials it is difficult in fusion welding. To reduce that problem, researchers used a solid-state technique for welding such as Friction stir welding. The tool geometry and its parameters play a crucial role in the welding for better mechanical properties and good weld joint. The plastic deformation of the material in friction stir welding process depends on the tool size; heat generation depends on the shoulder size; the grain size and morphology depend on the heat generated at the weld joint. The main aim of this review is to discuss the tool geometry and their parameters used mostly and mechanical properties to have a good weld joint.**

***Index Terms*—Friction stir welding, process parameters, tool geometry, tool materials.**

I. INTRODUCTION

"Friction Stir Welding (FSW)" is a recently and flexibility. It is mainly developed for the joining difficult to weld materials. The use of this welding is more in applications such as aircraft, marine, automobiles, railway, and aerospace industries. It is a more suitable process for the fusion welding process which is susceptible to hot cracking and embrittlement. Figure 1 shows the schematic of different stages of the FSW process. First of all, the geometry of the tool, (such as tool pin height, the shape of pin profile) heat generation due to friction forces and metals the material. Secondly, the process parameters such as tool rotational speed, welding speed, tool tilt angle, etc., are selected to improve the results of proper microstructure and good tensile strength, fatigue strength, and ductility of the joint. Because of the flexibility and high energy efficiency, this welding process is more suitable for aluminum and its alloys. Due to its properties like the low melting temperature of the alloys, it is easy to weld by this process. Many researchers have done their research on the microstructure and mechanical properties of tool geometry and its base material. The shape of the tool pinning is used for the flow of plasticized material and affects weld properties.

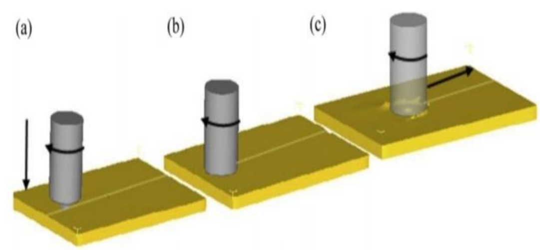

Figure1. Schematic stages of FSW process (a) plunging (b) dwelling (c) welding

NOMENCLATURE

FSW	Friction Stir Welding
AA	Aluminum Alloy
PCBN	Polycrystalline cubic boron nitride
WC	Tungsten carbide
W	Tungsten

II. PRINCIPLE OF FSW PROCESS

FSW is a solid-state welding process where a non-consumable rotating tool is used to generate frictional heat in the work piece with the frictional force and whose main parts are a pin with a shoulder arrangement. The heat produced due to friction between the tool and the plate when the tool moves over the plate. It plastically deforms and softens the material with proper mix from the leading face to the rear end. Because of the heat generation and mechanical deformation the tool causes local changes in welded material. The material temperature remains below the melting point during the process. In this process, two welded faces were present, the e., the advancing side, and the retreating side. The advancing side is known when the tool rotation direction and tool travel direction are the same. If they are opposite in direction to one another, that side is known as the retreating side. The FSW process is shown in figure 2.

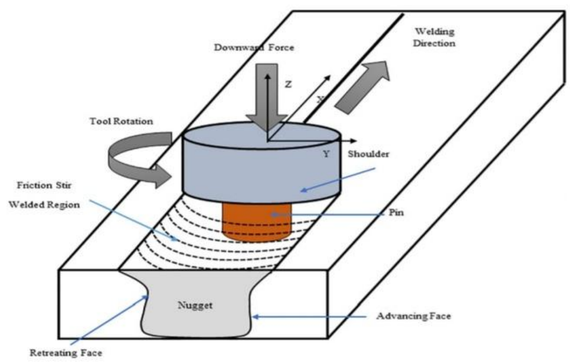

Figure2. Representative Diagram of working principle of FSW

III. EFFECT OF PROCESS PARAMETERS

The process parameters of FSW play an important role for the fabrication of quality weld joints with desired morphology and mechanical properties. Process parameters have a unique influence on the morphological and mechanical properties of each welded joint. The selection of the process parameters will depend on the mechanical and thermal properties of the base metal and the heating and cooling boundary conditions. In this study, the rotational speed and welding speed of tool, and tool tilt angle are taken into consideration as process parameters. Many authors have focused on different process parameters on dissimilar materials. Reference [2] showing the welding combination of Mg (AZ31) to Al (1050) alloys having a thickness of 6mm, tool traverse speed of 90 mm/min, the rotation speed of 2450 rpm, and the tool tilted at 3 from the normal direction of plate. The analysis of microstructure for weld joint is done by the optical microscope and showed a crack like the formation of an intermetallic compound due to the hardness at the center of stir region at stir zone. Reference [3] founded a defect in the weld zone when fabricated Al (5052) to Mg (AZ31B (O)) alloys having tool rotation and transverse speed of 800 rpm and 300 mm/min respectively with 2mm thickness of plate. When the rotation speed was increased from 1000 rpm to 1400 rpm with the same transverse speed, there was no defect found, when the rotation speed increased to 1600 rpm they found a crack at the stir zone. The range of process parameters have a good quality weld; having a high heat input to ensure sufficient material plasticity without reducing excessive weld properties in the resulting weld. The spindle speed which is one of the process parameters, when it is increased the hardness level at the base of the weld will also increase more than at the top, so the hardness value will converge at high spindle speeds. The hardness of the stir zone will increase with the tool’s rotational speed. The tool rotational speed increases results in a lower cooling rate because of the stir zone which is reached higher temperature. The properties of the joints welded at lower rotational speed are higher than the higher rotational speed. The higher tool rotational speed results in excess heat in the heat-affected zone and the lowers tool rotational speed results in causing defects due to the insufficient material flow in the stir zone. Improper selection of process parameters leads to excess supply of heat during the process which in turn causes an excess flash of material flow at the joint. Reference [4] shows the higher value of strength at weld joint is produced by providing the tool offset to Mg alloy plates, and lower strength of weld was found when the tool was offset near the Al alloy plates. Lower heat reduces the mixing of material at the stirring zone and whereas higher heat reduces the strength of welded material. At higher tool rotation rate and tool shoulder diameter generate more heat and whereas high tool traverse speed generates less heat.

IV. EFFECT OF TOOL GEOMETRY

Recently, many researchers have investigated the tool effect in the process of friction stir welding. The tool which is rotating serves 3 main functions, i.e. heating of the work piece, movement of material to produce the joint, and containment of the heated metal beneath the tool shoulder. The tool geometry plays a very essential for free defect joints and good weld quality. The tool geometry has 2 main important parts i.e. pin and shoulder. The tool profile affects the material flow, strength, and quality of weld joint. The material flow generated is important to have a cavity-free weld joint. The shoulder generates most of the heat and also prevents the plasticized material from escaping the work piece surface. The tool geometry is the most essential process parameter to affect to the welding joints. Different tool geometry will have different mechanical and morphological properties. There are different types of tool shoulders and tool pin profiles are used in friction stir welding. Generally, flat surface, concave surface, and convex surfaces are used with various kinds of pin profiles, such as straight, taper, cylindrical threaded, triangle, and square pin profiles shown in figure 3. For the selection of tool material, we have to consider durability and having a greater melting temperature of tool material than the heat generated. [1] Mukherjee et al. explained various tool materials which are generally used in the FSW process and decide by the mechanical properties of the base material like tool steels, PCBN, Ni-alloys, W-alloys, WC composite, and WC-Co. The following table explains briefly the tool materials.

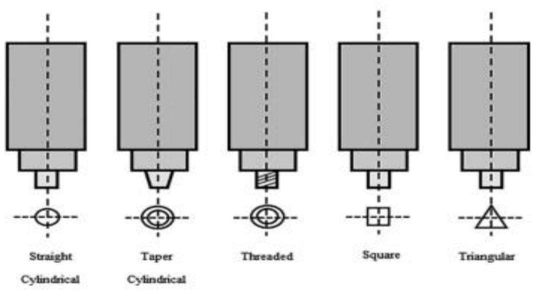

Figure3. Tool geometry with a different type of tool shoulder and pin profiles

Table1. Tool Materials and Suitable Weld Metals

S.No.	Tool Material	Suitable Weld Material
1	Tool steels	Aluminum alloys and Copper alloys
2	PCBN	Copper alloys, Stainless steel, and Nickel alloys
3	Ni-Alloys	Copper alloys
4	W-Alloys	Titanium alloys, Stainless steel, and copper alloys
5	WC composite	Aluminum alloys, Low alloys steel and Magnesium alloys, Titanium alloys
6	WC- Co	Aluminum alloys and Mild steel

The important effects of the tool during welding: are dynamic effect, high temperature, and abrasive wear. Good tool materials must have some properties like good wear resistance, temper resistance, good toughness, and high-temperature strength.

V. CONCLUSIONS

The review of this paper is done and the following effect of process variables and the effect of tool profile can be found on the microstructure and mechanical properties:

- The optimum range of process parameters has been established as a defect-free weld. For example, Tool Rotation Speed: 1400 rpm; Tool Traverse Speed: 40 mm/min; Tool Tilt Angle: 3º.
- The different Tool Geometry was reviewed and future research works can be done as per the requirement of the study.
- A pin-less tool geometry of the FSW process can produce cracks at the weld line.
- Various tool materials were also reviewed and categorized as per the materials to be welded.

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