Review paper on friction stir welding

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Abstract- *Friction stir Welding is the type of welding used as a solid state joining process for materials that is different alloys of aluminum, magnesium etc. and also for hard materials like steels because it deflects the common problems obtained in conventional welding processes. The reality that joining of alloys could be usually faced problems in many sectors that includes automotive, aerospace, ship building industries, electronics etc. where fusion welding is not possible due to large difference in physical and chemical properties of the components to be joined. Difficulties in conventional welding processes is porosity formation, solidification cracking, and chemical reaction may arise during welding of dissimilar materials although sound welds may be obtained in some restricted cases with special aids to the joint design and preparation, process factors and filler metals.*

Key Words: **Alloys, FSW, HAZ, Materials, Tool, Temperature Distribution, Welding**

1.INTRODUCTION

FRICTION STIR WELDING (FSW) was invented in 1991 at The Welding Institute (TWI) of the United Kingdom as a solid-state material joining process and this was initially applied to aluminum alloys. The basic of friction stir welding working is simple a non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of two plates to be joined and subsequently traversed along the joint line definitions for the tool and work piece as shown in Fig.1. Most definitions are self-explanatory, but advancing and retreating side definitions require a brief explanation. Advancing and retreating side orientations require knowledge of the tool rotation and travel directions. [1]

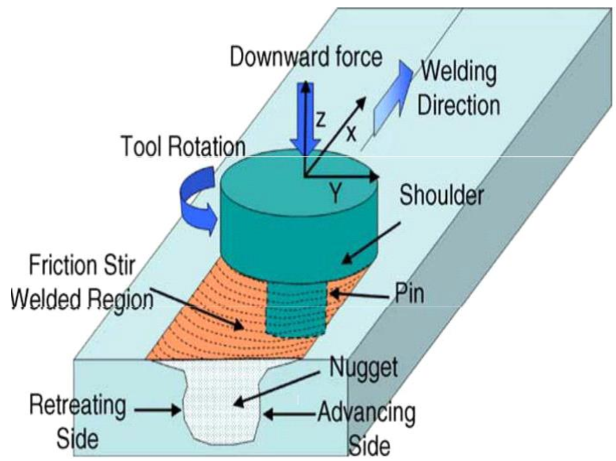

Fig.1 frictions stir welding Process

The factors which influence on the friction stir welding are as fallows [2]
1. Rotational Speed
2. Welding Speed
3. Pressure on Tool (Down Force)
4. Tilting Angle

The effect of each of the parameter is as shown in below Table 1.

Table -1: FSW PARAMETERS FOR MECHANIZED WELDING

Sr No.	Parameters	Effect of parameters
1	Rotational Speed	Frictional heat, stirring, oxide layer breaking and mixing of material
2	Welding Speed	Appearance, heat control.
3	Pressure on tool (Down Force)	Frictional heat, maintaining contact conditions
4	Tilting Angle	The appearance of the weld, thinning

Essential facts in FSW process are
1. Tool Material
2. Tool design
3. Temperature Distribution
4. Microstructure Development
5. Mechanical Properties
6. Process Modeling

1.1 Materials for Welding

In the procedure of friction stir welding the material selection is vital portion from the base materials the other restrictions are certain like tool material, rotational speed, down force, translational speed. By using FSW process rapid and high quality welding of 2xxx and 7xxx series of alloys, traditionally measured un-weldable now develop likely with this process. In terms of high-temperature materials, FSW has been a successful of alloys and materials like [13]
1. Copper and its alloys
2. Lead
3. Titanium and its alloys
4. Magnesium alloys
5. Zinc
6. Plastics
7. Mild steel
8. Stainless steel
9. Nickel alloys

2. TOOL MATERIAL

Afterwards the selection of base material also the vital restriction in FSW process is selection of tool materials and shape of tool pin, shoulder. The tool produces the thermo mechanical deformation and work piece frictional heating necessary for friction stirring. When the down force is applied on tool then tool is introducing in the base materials. The friction stirring tool contains of a pin or probe, and shoulder. Contact of the pin with the work piece produces frictional and deformational heating and moderates the workpiece material contacting the shoulder to the workpiece increases the workpiece heating, expands the zone of softened material, and constrains the deformed material.

2.1 Tool Material Characteristics

Selecting the correct tool material requires knowing which material characteristics are important for each friction stir application. Many different material characteristics could be considered important to friction stir welding process.

1. Wear Resistance
2. Coefficient of Thermal Expansion
3. Ambient- and Elevated-Temperature Strength
4. Elevated-Temperature Stability.
5. Tool Reactivity
6. Fracture Toughness
7. Machinability
8. Uniformity in Microstructure and Density
9. Availability of Materials.

2.2 Materials

Tool materials scheduled for friction stir welding and processing. The scheduled tool materials should not be viewed as an extensive list, because many papers do not specify the tool material or right the tool materials are proprietary. Table 2 is a summary of the current tool materials used to friction stir the indicated materials and thicknesses. These data are assembled from the indicated literature sources. [5, 6, 14]

Table 2
Summary of Current Friction Stir Welding Tool Materials with Their Forging Temperature.

Alloys	Tool materials	Forging temperature in 0c
Aluminum alloys	Tool steel, WC-Co	440-560
Magnesium alloys	Tool steel, WC	250-340
Copper and copper alloys	Nickel alloys, PCBN(a),tungsten alloys, Tool steel	600-910
Titanium alloys	Tungsten alloys	700-360
Stainless steels	PCBN, tungsten alloys	860-1030
Low-alloy steel	WC, PCBN	650-810

1. Tool Steels

Tool steel is the most common tool material used in FSW. This is because a majority of the published FSW literature is on aluminum alloys, which are easily friction stirred with tool steels. The advantages to using tool steel as friction stir tooling material include easy availability and machinability, low cost, and established material characteristics.

2. Nickel- and Cobalt-Base Alloys

For to have high strength, creep resistance, ductility, and corrosion resistance the high temperature nickel and cobalt base alloys were developed. These alloys derive their strength from precipitates, so the use temperature must be kept below the precipitation temperature (typically 600 to 810 °C) to prevent precipitate over aging and dissolution.

3. Carbides and Metal-Matrix Composites

Carbides are commonly used as machining tools due to superior wear resistance and reasonable fracture toughness at ambient temperatures. Because they are made for machining tools, carbides perform well at elevated temperatures. Friction stirring tools made from tungsten carbide are reported to have smooth and uniform thread surfaces for the FSW.

4. Cubic Boron Nitride

Polycrystalline cubic boron nitride was originally developed for the turning and machining of tool steels, cast irons, and super alloys

3. TOOL DESIGN

Heat generation rate, traverse force, torque and the thermo mechanical environment experienced by the tool geometry. The flow of plasticized material in the work piece is affected by the tool geometry as well as the linear and rotational motion of the tool. Important factors are shoulder diameter, shoulder surface angle, pin geometry including its shape and size and the nature of tool surfaces.

1. Shoulder Diameter

The diameter of the tool shoulder is important because the shoulder generates most of the heat, and its grip on the plasticized materials largely establishes the material flow field. Both sliding and sticking generate heat where as material flow is caused only from sticking. For a good FSW practice, the material should be adequately softened for flow, the tool should have adequate grip on the plasticized material and the total torque and traverse force should not be excessive.

2 Shoulder Surface

The nature of the tool shoulder surface is an important aspect of tool design. The studied flat, convex and concave tool shoulders, and cylindrical, tapered, inverse tapered and triangular pin geometries. They found that triangular pins with concave shoulders resulted in high strength spot welds. Examined the role of geometric parameters of convex shoulder step spiral (CS4) tools and identified the radius of curvature of the tool shoulder and pitch of the step spiral as important geometric parameters. Shoulder Features the FSW tool shoulders can also contain features to increase the amount of material deformation produced by the shoulder, resulting in increased work piece mixing and higher-quality friction stir welds these features can consist of scrolls, ridges or knurling, grooves, and concentric circles and can be machined on to any tool shoulder profile (concave, flat, and convex).

3 Pin (Probe) Geometry

The shape of the tool pin (or probe) influences the flow of plasticized material and affects weld properties. Welding tool design is critical in FSW.

Optimizing tool geometry to produce more heat or achieve more efficient “stirring” offers two main benefits: improved breaking and mixing of the oxide layer and more efficient heat generation, yielding higher welding speeds and, of course, enhanced quality. [7,11]

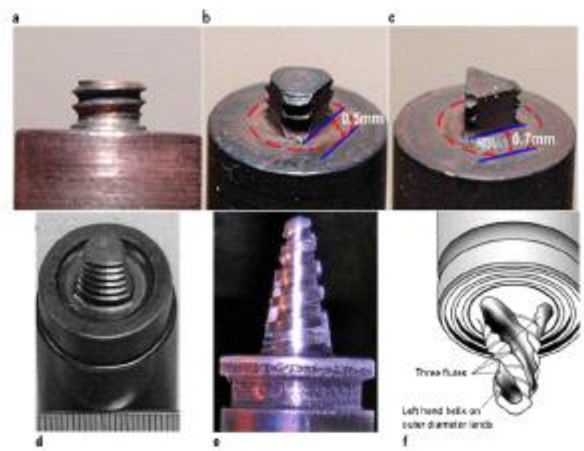

Fig.2 Commonly Used Pin Geometries A)Cylindrical Threaded B) Three Flat Threaded C)Triangular D)Trivex E)Threaded Conical F) Schematic of a Triflute.

4 Complex Motion Tools

The recent study on FSW tool design that increases the tool travel speed, increase the volume of material swept by pin-to-pin volume ratio, and/or increases the weld symmetry. Many of these tool designs have focused on tool motion and not specifically on the tool pin design, although each type of complex motion can have an optimal tool design. Most complex motion tools require specialized machinery or specially machined tools, making these tools unsuitable for basic applications. [2]

1. Skew-Stir Tool
2. Com-Stir tools

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3. Dual-Rotation Tool
4. Re-Stir Tool

TABLE.3 COMPLEX MOTION TOOL

Sr. no.	Type of Tool	Description of the type of tool
1.	Skew-Stir Tool	increase the volume of material swept by pin-to pin volume ratio by offsetting the axis of the pin from the axis of the spindle
2.	Com-Stir tools	combine rotary motion (tool shoulder) with orbital motion (tool pin) to maximize the volume of material swept by pin-to-pin volume ratio
3.	Dual-Rotation Tool	the pin and shoulder rotate separately at different speeds and/or in different directions
4.	Re-Stir Tool	1. Avoids the inherent asymmetry produced during friction stirring by alternating the tool rotation, either by angular reciprocation (direction reversal during one revolution) or rotary reversal (direction reversal every one or more revolutions) 2. Alternating the tool rotation produces alternating regions of advancing and retreating side material through the length of the weld, thus eliminating the asymmetry issues

4. Temperature Distribution

Heat is generated by a combination of friction and plastic dissipation during deformation of the metal. The dominating heat generation mechanism is influenced by the weld parameters, thermal conductivities of the work piece, pin tool and backing anvil, and the weld tool geometry and also depend on the contact conditions between the two surfaces. The weld tool geometric features of both the pin and the shoulder influence whether the two surfaces slide, stick, or alternate between the two modes.

For the Detailed temperature measurements with embedded thermocouples (TCs) have been used to map out the temperature field Interpretation of these measurements is affected by the coupled thermal conductivity of the work piece, the backing anvil, and the weld tool Depending on the TC location, embedded TCs near the pin tool are generally consumed in the weld process. [3]

The below Fig.3 shows the transverse section of a FSW welding process with zones on the material

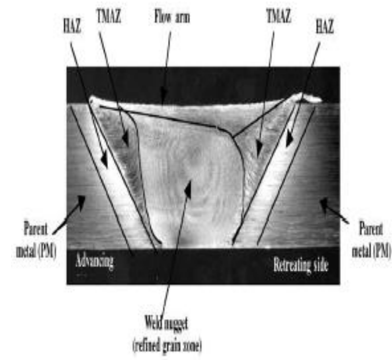

Fig. 3 Transverse section of a friction stir welds showing different regions of the weld. HAZ, heat-affected zone; TMAZ, thermo mechanically affected zone. [3]

5. MICROSTRUCTURE DEVELOPMENT

THE MICROSTRUCTURE and consequent property distributions produced during friction stir welding (FSW) of aluminum alloys are dependent on several factors. The contributing factors include alloy composition, alloy temper, welding parameters, gage of the welded plate, and other geometric factors. Alloy composition determines the available strengthening mechanisms and how the material will be affected by the temperature and strain history associated with FSW. The alloy temper dictates the starting microstructure, which can have an important effect on the alloy response to FSW, particularly in the heat-affected zone (HAZ). Welding parameters (e.g., tool rotation rate and welding speed) dictate, for given tool geometry and thermal boundary conditions, the temperature and strain history of the material being welded. [5]

6. MECHANICAL PROPERTIES

It is now known that properties following FSW are a function of both controlled and uncontrolled variables as well as external boundary conditions. For example, investigators have now illustrated that post weld properties can be a function of:

1. Tool travel speed
2. Tool rotation rate
3. Tool design
4. Tool tilt
5. Material thickness
6. Alloy composition
7. Initial material temper
8. Cooling rate

9. Heat sink
10. Test sample size, location, and orientation
11. Surface oxides
12. Joint design
13. Post weld heat
14. FSW test system

The different mechanical properties are found from the above functional requirement of FSW processes.
1. Hardness
2. Yield Strength
3. Elongation
4. Fracture Toughness
5. Fatigue Crack Growth Rate.

7. PROCESS MODELING

PROCESS INNOVATIONS invariably evolve empirically, using accumulated experience from laboratory trials. In all process modeling, it is essential to keep the goals of the model in view and to adopt an appropriate level of complexity. Analytical and numerical methods each have a role to play, although numerical methods dominate due to the power and ease of use of modern workstations and software.

Numerical modeling is based on discretized representations of specific welds, using finite element, finite difference, or finite volume techniques. These methods can capture much of the complexity in material constitutive behavior, boundary conditions, and geometry, but the computational penalty means that, in practice, a limited range of conditions tends to be studied in depth.

Some important stages in process modeling are
1. Analytical Estimates of Heat Generation
2. Heat Conduction
a. Analytical Methods
b. Numerical Methods
c. Experimental Validation
3. Metal Flow
a. Analytical Flow Modeling
b. Numerical Flow Modeling
c. Tool Material Interface Conditions
d. Influence of Tool Profile and Process Conditions
e. Experimental Flow Validation
4. Microstructure and Property Evolution in FSW
5. Residual Stress

8. CONCLUSIONS

FSW is the best process to welding of different alloys of aluminium for long lengths with an excellent quality. Considerable effort is being made to weld higher temperature materials such as alloys of magnesium, titanium and steels by using FSW. Take the process beyond its current use of mainly simple butt and lap joint configurations and make it a much more flexible fabrication process.

The different types of tool are used for the welding as per base materials forging temperature. Friction stir welding owing to its unique characteristics: low distortion and shrinkage even in long welds, free of arc, filler metal, and shielding gas, low HAZ, free of spatter and porosity defect is emerging as an alternative to fusion welding.

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