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A comprehensive review on Friction stir welding of aluminium alloys

Ch.Ratnam[1], B.Sudheer kumar[2], K.N.D.Malleswara Rao[3]

[1]*Professor and head of mechanical engineering, Andhra University, Visakhapatnam, India.*
[2]*Assistant professor, Department of Mechanical Engineering, Andhra Loyola Institute of Engineering and Technology, Vijayawada, India.*
[3] *Assistant professor, Department of Mechanical Engineering, Lakireddy Bali Reddy college of Engineering (A)*, Mylavaram.

Abstract: *Friction stir welding is a novel process used to join metallic alloys, moreover very vogue in automotive industry and aerospace for connecting alloys like aluminum and copper. The process is also an effective method for joining dissimilar materials. However, the process has still not found an economical way for welding of aluminium alloys and hence found limited applications in industries for welding aluminium alloys. This paper focusing on providing a complete review of the work undertaken in the field of friction stir welding of aluminium alloys moreover pays critical attention and evaluation of classification of aluminium alloys and friction stir welding process parameters.*

Keywords- *Friction stir welding, aluminium alloys, FSW tool geometry, process parameters of FSW.*

I. INTRODUCTION

Welding is a critical manufacturing process that produces a complex design of parts which are difficult to form. With this, the importance of welding has grown substantially in recent years and is now treated as one of the most demanded manufacturing processes [1-3]. Whereas friction stir welding is a method of solid phase welding, which allows a wide range of parts and geometries to be welded and was invented by W Thomas and his colleagues at The Welding Institute, in 1991.
The process is undertaken in the solid state and hence its most significant advantage is in welding of aluminium alloys (2xxx and 7xxx series) which are extremely sensitive to weld [4,5]. Friction stir welded joints are free from any kind of filler or slag inclusions [6-8]. They are also less susceptible to hydrogen absorption and hence not vulnerable to hydrogen cracking, which is one of the important considerations while welding aluminium alloys [9, 10].
In order to evaluate aluminium alloys superplastic behavior Dieguez et al. [11] were able to produce a refined area with an average grain size of 4.65 mm by friction stir processing of Al 7075-T651 aluminium alloys. Whereas Garcia-Bernal et al. [12] investigated the effect of tool design on the superplastic behavior of friction stir processed Al-Mg alloys. They found maximum tensile elongations in the range of 575–810% with three different tool designs.
In a similar kind of investigation, Patel et al. [13] studied the effect of various pin profiles on the temperature distribution around the tool during the plunge stage in FSP of Al–Zn–Mg–Cu alloy. And Malopheyev et al. [14] friction stir welded Al 7075 alloys to evaluate the superplasticity of the obtained joints.
Salem et al. [15] demonstrated the ability of superplastic, rolled sheets of Al 2095 aluminium alloys to retain its superplasticity even after friction stir welding. Whereas Sun et al. [16] used a laser heating source to preheat S45C steel plates during FSW and concluded that a particular position of the laser beam permits uses of almost double the welding speed compared to normal FSW. [17] Bang H et al. investigated the Use of a welding heat source in form of preceding gas tungsten arc during FSW of dissimilar Al6061-T6 aluminium alloy and titanium alloy resulted in higher joint strength and better temperature distribution compared to conventional friction stir welded joints welded using the same weld conditions.

II. CLASSIFICATION OF ALUMINIUM ALLOYS

Aluminium alloys are basically classified into two types:

- Nonheat treatable alloys and
- Heat treatable alloys.

2.1 Nonheat treatable aluminium alloys

Nonheat treatable alloys are a group of alloys that do not show any response to strengthening by heat treatment. Strength is developed by strain hardening by cold working and solution hardening (alloying) [18].

2.2 Heat-treatable aluminium alloys

They are the category of wrought alloys that respond to strengthening by heat treatment. The enhanced strength of the heat-treatable aluminum alloys is attributed to age hardening. [19] The major alloying elements of various aluminium alloys are shown in Table 1.

Table 1. Major alloying elements for various aluminium alloys.

Alloy Series	Major alloying element
1xxx	Pure Aluminium
2xxx	Copper (1.9–6.8%)
3xxx	Manganese (0.3–1.5%)
4xxx	Silicon (3.6–13.5%)
5xxx	Magnesium (0.5% to 5.5%)
6xxx	Magnesium and Silicion (Mg 0.4–1.5%, Si 0.2–1.7%)
7xxx	Zinc (1–8.2%)

III. FRICTION STIR WELDING TECHNIQUE

FSW utilizes a rotating welding tool (non consumable) with a specially designed pin and shoulder. The base plates to be joined are clamped rigidly in proper joint configuration. The tool is rotated at a constant speed and gradually plunged into the adjoining edges of the plates to be joined until the tool shoulder makes sufficient contact with the surface of the plates to be welded. The shoulder rubs against the surface of workpiece breaking the surface oxide layer and heating the material. Thus, FSW is a solid-state joining technique in which the plates are mechanically joined by frictional heating and severe mechanical deformation [20]. The principle of FSW is shown in Figure 1.

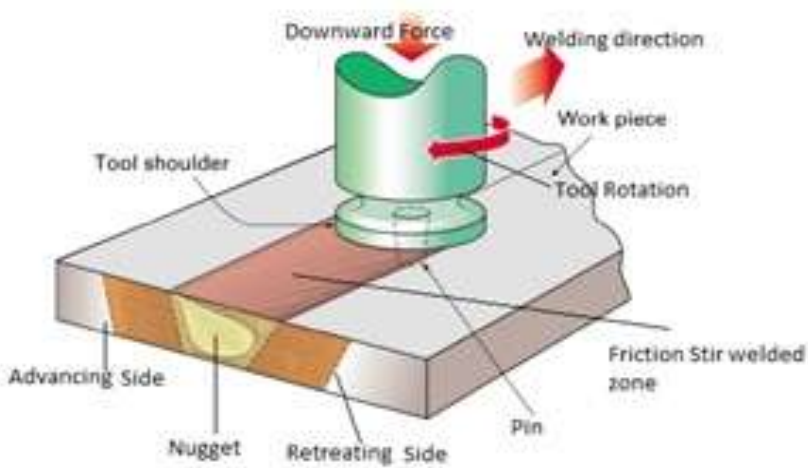

Figure 1. Schematic view of FSW

3.1 Important Advantages of FSW

- The FSW is a solid-state process that occurs below the melting point of the materials to be welded.
- Dissimilar composites and aluminum alloys can be welded with equal ease.
- It does not involve the use of filler metal and hence the weld can be undertaken without any considerations on the compatibility of the composition of the filler wire and weld alloys.
- Since the process is undertaken in the solid state, weld defects such as shrinkage and porosities are not found in friction stir welded joints.

3.2 FSW machine

The machine tool for FSW requires the rotation of the FSW tool along with its feed movement. The plunging of the tool is done in the Z-axis. The machine must be capable of generating variable speeds and feed rates. The movement of each axis is powered by electric motors and gearboxes to generate the required torque [20].

3.3 FSW tool

The tool in FSW is a vital component in FSW and largely contributes to the success of the process. It primarily consists of two parts namely the shoulder and the pin [20]. The shoulder mainly does the function of frictionally heating the workpiece material by rubbing against the work material. It also confines the heated volume of material within the weld zone. The tool pin functions to plastically deform the material being joined. The pin ‘‘stirs’’ and ‘‘moves’’ the Material [21]. The quality of the microstructure and the mechanical properties of the joint are governed by the tool design.

3.4 FSW tool materials.

The tool materials used for welding of a variety of materials are tool steels (viz. high carbon high chromium steels, AISI H13, HSS-M2), nickel and cobalt base alloys, refractory metals (like tungsten, tantalum, molybdenum), carbides, and pcBN. [22]

3.5 FSW tool geometry.

In order to improve the heat generation and material flow, both the shoulder and the pin are provided with certain features and profiles. Normally three types of forms viz. convex, concave, and flat are used as shoulder end surfaces [20]. Various shoulder profiles such as scrolls, concentric circles and grooves are designed underneath the tool shoulder to increase the coupling effect between the shoulder and the workpiece. Figure 2 shows various shapes and profiles of the tool shoulder as reported by Zhang et al. [23] whereas Figure 3 shows various pin shapes and profiles of friction stir welding.

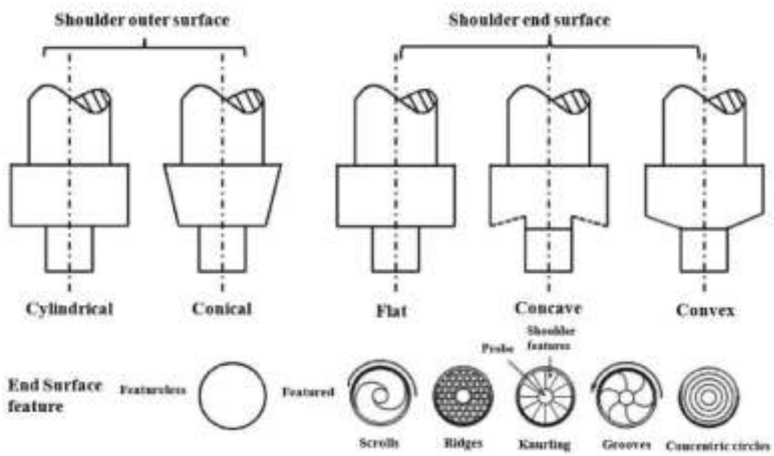

Figure 2. Various shoulder shapes and features of friction stir welding tool.

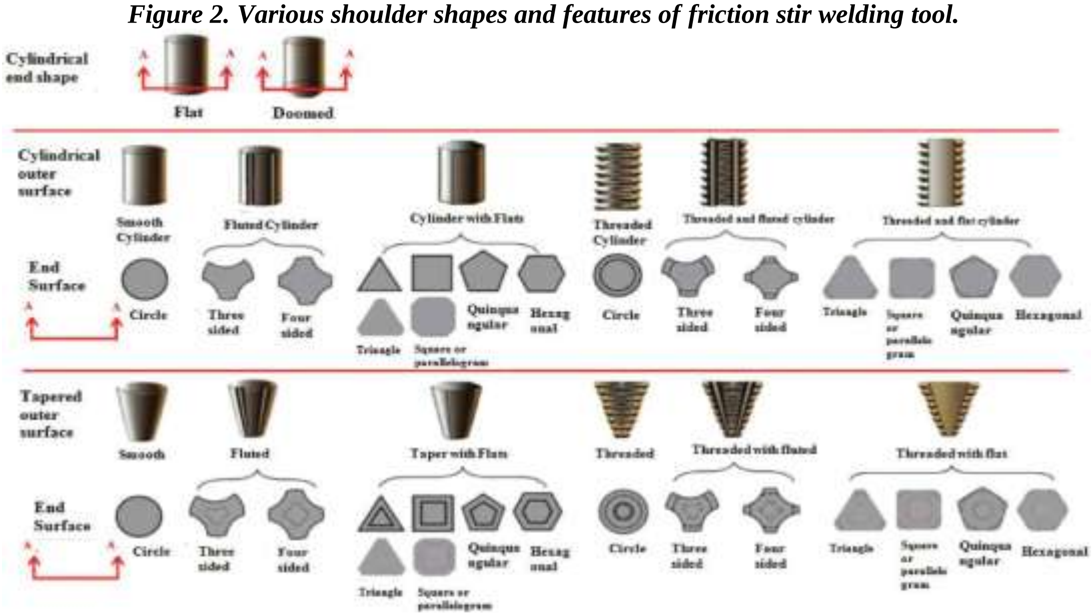

Figure 3. Various pin shapes and profiles of friction stir welding.

3.6 FSW tool wear.

The importance of the dimensional stability of the FSW tool during the process is of utmost importance. The translation and rotation of the tool through the workpiece often result in wear of tool as a result of which the tool may lose its shape. The tool is likely to lose its shape by plastic deformation due to the reduction in the yield strength at high temperatures. Tool failure may occur if the stresses increase more than the load-bearing capacity of the tool [20].

IV. PROCESS PARAMETERS OF FSW

- The tool rotation speed, the welding (tool traverse) speed, the axial pressure, the tool tilt angle, and the tool design are the major independent variables that control the FSW process.21,22,24,25 The tool rotational speed mainly does the function of frictional heating, stirring and breaking of the oxide layers on the top surface of the plates. But higher heat input does not always guarantee higher joint strength. Increasing the tool rotation speed for a constant tool pin diameter reduces the fatigue strength of the joints while increasing the tool pin diameter for a constant tool rotation speed also reduces the fatigue strength of the joints. The maximum fatigue strength was found with minimum tool rotation speed and tool pin diameter. Weld pitch is the ratio of welding speed to tool rotational speed. While the shoulder of the tool is mainly responsible for the stirring of the material at the surface of the workpiece, the vertical mixing within the stir zone occurs due to the threading on the tool [20].
- Axial pressure also plays a vital role in dictating weld quality. Too low axial force results in inadequate heat generation leading to defects such as surface breaking discontinuity or void formation. On the other hand, too high axial pressure results in excessive overheating, concaving and thinning of the joint which can ultimately lead to excessive flash generation [20].
- Providing a tilt angle to the tool helps in re-coalescence of stirred material at the rear end of the tool. [22] Greater tilt angles tend to lift the bottom of the pin from the root of the weld thereby decreasing the target depth leading to insufficient stirring at the root causing defects at the root of the weld. The effect of various variables/combination of variables on the weld quality of different aluminium alloys has been reported by many researchers. The readers can find more elaborate discussions on this matter in the literature (but not limited to). [26, 27]

V. OPTIMIZATION MODELS USED IN FSW

The parameter selection largely depends on the composition of the material, the plate thickness, and the type of joint to be welded. In order to achieve a good quality weld, the process should be carried out at optimum levels of parameters from the available range on the machine [20].
Suresha et al. [28] used Taguchi orthogonal array L9 to study the effect of tool pin profiles on the tensile strength of FSW welded joints. They employed signal to- noise (S/N) ratio and analysis of variance (ANOVA) to find the percentage contributions of welding parameters tool rotational speed, traverse speed, and plunge depth on the tensile strength of the AA 7075-T6 FSW joints. Javadi et al. [29] used the Taguchi method as the statistical design of experiment (DOE) for optimization of residual stresses produced by friction stir welding of 5086 aluminium plates. By using ANOVA, it has been concluded that the feed rate most significantly affects the longitudinal residual stress peak.
Furkan et al. [30] determined the impact of parameters such as spindle rotational speed, traverse speed, and stirrer geometry on ultimate tensile strength and hardness of FS welded AA 1050/AA 5083 alloy by conducting full factorial experiments. They used ANOVA and main effect plots to determine the significant parameters and set the optimal level for each parameter.

VI. CONCLUSION

The present review has been undertaken, with an objective of friction stir welding of aluminium alloys materials and to study classification of aluminium alloys and friction stir welding process parameters. Compared to the conventional fusion welding process, friction stir welding is found to be a very useful and economical technique for joining aluminium alloys because of the considerable improvement in ductility, strength, fatigue and fracture toughness. Tool designs are very important factors for producing the good and defect-free weld. In the present review friction stir welding process parameters such as tool rotational speed, welding speed, spindle tilt angle and tool type should be conduct for improving the ultimate tensile strength and percentage elongation of friction stir welding joint by choosing optimum weld parameters.

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