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Friction Stir Welding – Process Parameters and its Variables: A Review

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Abstract: ***Friction Stir Welding (FSW) was invented by Wayne Thomas at TWI (The Welding Institute), and the first patent applications were filed in the UK in December 1991, that utilizes a non-consumable rotating welding tool to generate frictional heat and plastic deformation at the welding location; there by, affecting the formation of a joint while the material is in the solid state. Friction stir welding (FSW) is the latest technology in the area of metal joining and is perhaps the most promising of all the welding processes. A lot of research has been carried out in this area but most of the initial work has been done on low temperature softening materials like aluminium alloys. Friction Stir Welding (FSW) has become a major joining process in the railway, aerospace, auto industries and ship building industries especially in the fabrication of aluminium alloys. The process uses a spinning non-consumable tool to generate frictional heat in the work piece. This paper looks at the review, on friction stir welding process, various welding variables like tool rotation, transverse speed, tool tilt, plunge depth and tool design, for the welding of aluminium alloys or various dissimilar alloys. Applications are also described.***

Keywords: Friction Stir Welding, tool rotation and transverse speed, tool tilt and plunge depth.

1. Introduction

The history of joining metals goes back several millennia, with the earliest examples of welding from the Bronze Age and the Iron Age. From that time the process of welding gone through several modifications, world wars caused a major surge in the use of welding processes, with the various military powers attempting to determine which of the several new welding processes would be best. Many sophisticated welding methods for different alloys of variety applications are available now. Friction stir welding (FSW) is a solid state process for joining materials, especially dissimilar materials, which involves generation of heat by the conversion of mechanical energy into thermal energy at the interface of the work pieces without using electrical energy or heat from other sources during rotation under pressure. As a high-quality, precise, high-efficiency, energy-saving and environmental-friendly technique,

FSW has been widely used in the aerospace, shipbuilding, automobile industries and in many applications of commercial importance. Some of the advantages over the conventional welding techniques are very low distortion, no fumes, porosity or spatter, no consumables, no special surface treatment and no shielding gas requirements. It enables to weld almost all types of aluminium alloys, even the one classified as non-weldable by fusion welding due to hot cracking and poor solidification microstructure in the fusion zone (Zimmer Sandra et al., 2009). Using FSW, rapid and high quality welds of 2xxx and 8xxx series alloys, traditionally considered un-weldable, now become possible. The key benefits of FSW are summarized below, (Mishra R.S. et al., 2005).

Key benefits of FSW are summarized below:

A. Metallurgical benefits

- Low distortion of work piece
- Fine microstructure
- Solid phase process
- Good dimensional stability and repeatability
- No loss of alloying elements
- Absence of cracking

B. Environmental benefits

- No surface cleaning required
- No shielding gas required
- No grinding, brushing or pickling is required
- Consumable materials saving, such as rugs, wire or any other gases

C. Energy benefits

- Improved materials use (e.g., joining different thickness) allows reduction in weight
- Decreased fuel consumption in light weight aircraft automotive and ship applications
- No fusion or filler material is required

2. II FSW the process:

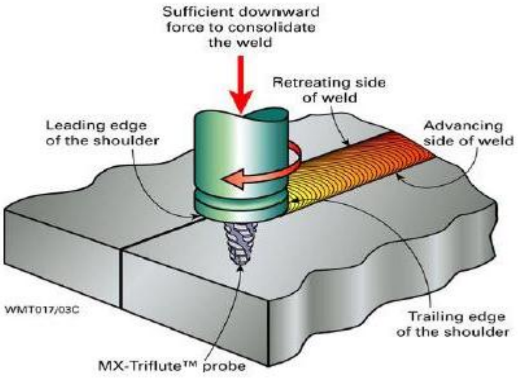

Figure 1: The principle of Friction Stir Welding

In FSW, a cylindrical shouldered tool with a profiled pin is rotated and plunged into the joint area between two pieces of sheet or plate material. The parts have to be securely clamped to prevent the joint faces from being forced apart. Frictional heat between the wear resistant welding tool and the work pieces causes the latter to soften without reaching melting point, allowing the tool to traverse along the weld line. The plasticized material, transferred to the trailing edge of the tool pin, is forged through intimate contact with the tool shoulder and pin profile. On cooling, a solid phase bond is created between the work pieces.

Tool size and shape is most important variable, to get defect free welds. Tool should have minimum pin diameter but high frictional surface to limit stirring area. It should have sufficient size to provide adequate heating of stirred area and have resistance against failure by shear. Shoulder should have adequate size to retain the hot worked material and to compress it on the rear side. Smaller size of shoulder diameter can cause loss of material in form of flash and defective welds. On the other side excessively large shoulder diameter causes heavy loading on equipment.

Tools consist of a shoulder and a probe which can be integral with the shoulder or as a separate insert possibly of a different material. The design of the shoulder and of the probe is very important for the quality of the weld. The probe of the tool generates the heat and stirs the material being welded but the shoulder also plays an important part by providing additional frictional treatment as well as preventing the plasticized material from escaping from the weld region. The plasticized material is extruded from the leading to the trailing side of the tool but is trapped by the shoulder which moves along the weld to produce a smooth surface finish. Clearly, different materials and different thicknesses will require different profile probes and welds can be produced from just one side or by welding half the thickness then turning over to complete the other side. FSW tools are of three types namely fixed tool, adjustable tool and self reacting tool. Fixed tool is made of single piece and used to weld the work piece with constant thickness. To adjust the probe length during welding the shoulder and pin is made as two independent pieces in adjustable tool. Some typical type probes are shown in Fig. (2)

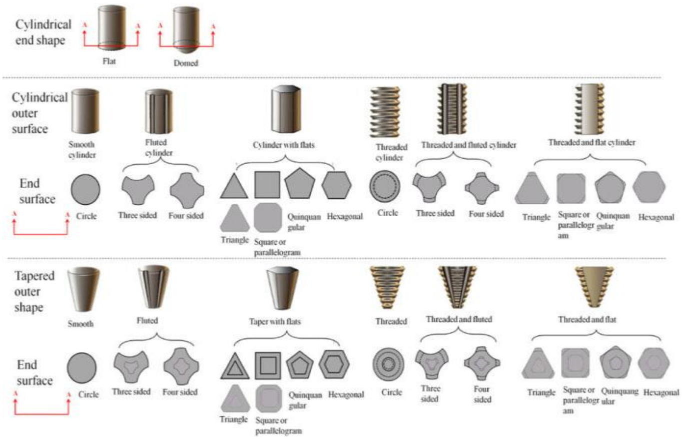

Figure 2: Different Shapes of Probes

3. Welding Parameters

There is a consensus that the most important welding parameter is the rotation speed, but that the transverse speed and plunge depth are also very significant. Rotation speed determines the heat input and temperature as well as the shear experienced by the FSW welds. Consequently, it influences the microstructure and mechanical properties of the FSW welds. Other welding parameters include tilt angle, spindle power, torque, Z force, as well as the distance between the FSW weld and the side of the plate. (Record et al. 2004; Dawes and Thomas 1999; Nandan et al. 2008; Mishra and Ma 2005; Gould et al. 1998; Surekha and Els-Botes 2011; Yan et al. 2004; Cederqvist 2011; Cederqvist 2006; Fehrenbacher et al. 2011; Ahmed et al. 2008; Dubourg et al. 2006) Many factors affect the process of FSW. Colligan and Mishra (2008) developed a conceptual model of the influence of different welding parameters on the FSW process.

Figure (3) shows the model of the relationships between different welding parameters and their effects.

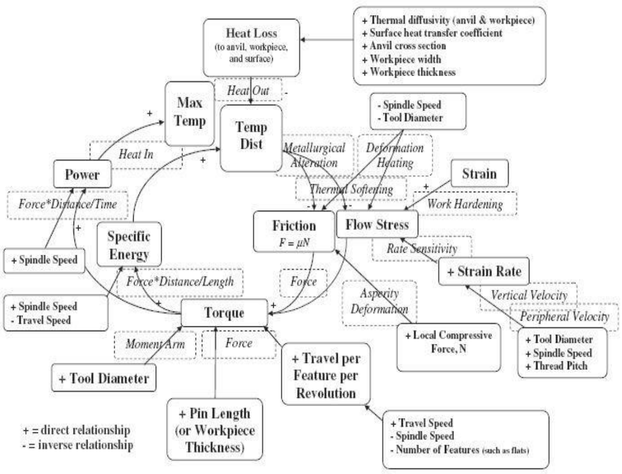

Figure 3: Conceptual model of the relationships between welding parameters and their effects

When using FSW, the following parameters must be controlled: down force, welding speed, the rotation speed of the welding tool and tilting angle. The main process parameters and there effects in friction stir welding are given below Table 1 (FSW-Technical- Handbook).

Table 1: Main process parameters in friction stir welding.

Parameter	Effects
Rotation speed	Frictional heat, “stirring”, oxide layer breaking and mixing of material
Tilting angle	The appearance of the weld, thinning
Welding speed	Appearance, heat control.
Down force	Frictional heat, maintaining contact conditions

4. Microstructure Classification

The first attempt at classifying microstructures was made by P L Threadgill (Bulletin, March 1997). This work was based solely on information available from aluminium alloys.]. For butt joints the generalized profile proposed by TWI was an inverted trapezoid with four zones which is shown in the fig. (4)

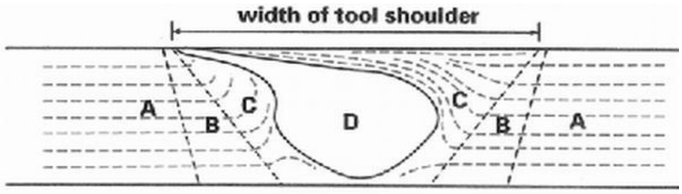

Figure 4: Microstructure of friction stir welded joint

Unaffected Material or Parent Metal (A): This is the material remote from the weld, which is neither deformed, nor affected by the heat in terms of microstructure or mechanical properties.

Heat-Affected Zone (HAZ) (B): It is common to all welding processes. As indicated by the name, this region is subjected to a thermal cycle but is not deformed during welding. The temperatures are lower than those in the TMAZ but may still have a significant effect if the microstructure is thermally unstable. In fact, in age-hardened aluminium alloys this region commonly exhibits the poorest mechanical properties

Thermo-Mechanically Affected Zone (TMAZ) (C): It occurs on either side of the stir zone. In this region the strain and temperature are lower and the effect of welding on the microstructure is correspondingly smaller. Unlike the stir zone the microstructure is recognizably that of the parent material, albeit significantly deformed and rotated. Although the term TMAZ technically refers to the entire deformed region it is often used to describe any region not already covered by the terms stir zone and flow arm.

Stir Zone (Nugget, Dynamically Recrystallised Zone) (D): It is a region of heavily deformed material that roughly corresponds to the location of the pin during welding. The grains within the stir zone are roughly equiaxed and often an order of magnitude smaller than the grains in the parent material.

5. Applications

1 Shipbuilding and marine industries: The process is suitable for the following applications:- Panels for decks, sides, bulkheads and floors, Hulls and superstructures, aluminium extrusions, helicopter landing platforms, marine and transport structures, refrigeration plant

2 Aerospace industries: The friction stir welding process can therefore be considered for: for welding in Al alloy fuel tanks for space vehicles, manufacturing of wings, external throw away tanks for military aircraft military and scientific rockets etc.

3 Railway industries: Applications in high speed trains, building of container bodies, railway tankers, etc.

4 Land transportation: Applications in automotive engine chassis, body frames, wheel rims, truck bodies, etc.

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