ISSN No.: 2455-6130
Volume 1, Issue 9, 2016, pp. 17-21

website: www.ijoetr.com

International Journal of Emerging Trends in Research

Friction Stir Welding: A Novel Joining Technique

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Abstract

Friction stir welding (FSW) is a relatively new technique which has been systematically developed for joining non-weldable aluminium alloys. This joining process is a more robust process for aluminium. It is proving to be far more tolerant to use then arc welding techniques and can consistently produce long welds, especially between extrusions, of high quality and with very low distortion. Consistent with the more conventional methods of friction welding, which have been practiced since the early 1950s, the weld is made in the solid phase, i.e. no melting. Since its invention, the process has received worldwide attention and today companies in Scandinavia, Japan, and the USA are using the technology in production, particularly for joining aluminium alloys. The objective of the present research article is to highlight the key points of FSW which make it different from other joining techniques. .

Keywords: friction stir welding; FSW; joining process; aluminium alloys

1. Introduction

In 1991 a novel welding method was conceived which was named *Friction Stir Welding* (FSW) by the inventors at The *Welding Institute* (TWI) (Dawes & Thomas, 1996; Thomas, 2012). The TWI is one of the world's leading independent research and technology organization and is based in *Cambridge, England*. A US patent for FSW was filed in November 1991 with W. H. Thomas et al. as inventors, assigned to TWI. A number of companies around the world are using the process in production, primarily for joining aluminum (Heinz et al., 2000; Thomas & Nicholas, 1997).

In friction stir welding a rotating cylindrical tool with a small pin is plunged slowly into the weld line of two plates clamped firmly in a fixture arrangement with a backing plate. The main components of friction stir welding— FSW machine, the cylindrical tool, and fixture; are shown a schematic diagram of friction stir welding process (figure 1) (Gibson et al., 2014; Sidhu & Chatha, 2012; Thoppul & Gibson, 2009). In this process tool shoulder plunged to the depth of material thickness, in this arrangement tool shoulder firmly contacted on the upper surface of the metal plates. As the feed is given to the workpiece table, the frictional heat between tool shoulder and the material's plate. The temperature rises due to plastic flow of material and the frictional heat generated by the relative speed of tool shoulder and tool pin with the material plates when the tool is plunged fullyinto thematerial. The total swept area of the tool on the welding plates is labeled as the 'tool shoulder footprint'.

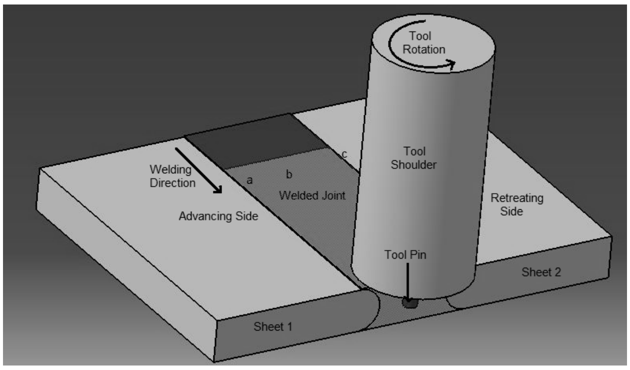

Figure 1: A schematic view of friction stir welding process

There are two sides of the rotating tool named— advancing side (AS) and retreating side (RS). In AS tool rotational speed and traverse movement are in the same direction but in RS tool rotational speed opposes the traverse speed (figure 1).

2. Mechanism of FSW

Friction stir welding is an intermixing of two material at recrystallization temperature so that the grains of two joining materials best placed mixed at ahigh temperature and high pressure. The high temperature is attained by the frictional force between tool and workpiece. High-pressure force is applied through axial loading of the tool during plunge of pin up to a maximum of material thickness. During the friction stir welding process, tool pin stirs semi-molten material at high rotational speed so that grains break and recover at different points of weld region (Kundu & Singh, 2016; Verma & Misra, 2015). These weld regions have been described by many researchers. Threadgill was one of the leading researchers who studied the microscopic features of friction stir welding of aluminium alloys and categorized into four visually distinct zones(Threadgill, Leonard, Shercliff, & P, 2009; Ulysse, 2002; Wu, Wang, Xiao, & Ma, 2014). These zones are distinguished in given figure 2 and recognized by American Welding Society in its standard list D17-3M.

i. Parent material or Unaffected material;
ii. Heat affected zone (HAZ);
iii. Thermo-mechanically affected zone (TMAZ); and
iv. Nugget zone or stir zone (NZ/SZ).

Unaffected parent material is at a remote distance from the welding zone. Although it bears some thermal cycles during the stirring process but there is not any significant change in the physical properties or the microscopic features of the base material. The heat affected zone is next near to the stirring area or the tool shoulder footprints. In this zone, thermal cycles alter the microstructure of the base material without any forced plastic deformation. Temperature variation experienced by the heat affected zone is very large but there is not any plastic deformation. Initially, this zone was named as thermal affected zone however by the analogy of other welding processes the term HAZ well understood. The thermo-mechanically affected zone is plastically deformed by the processing of the material.

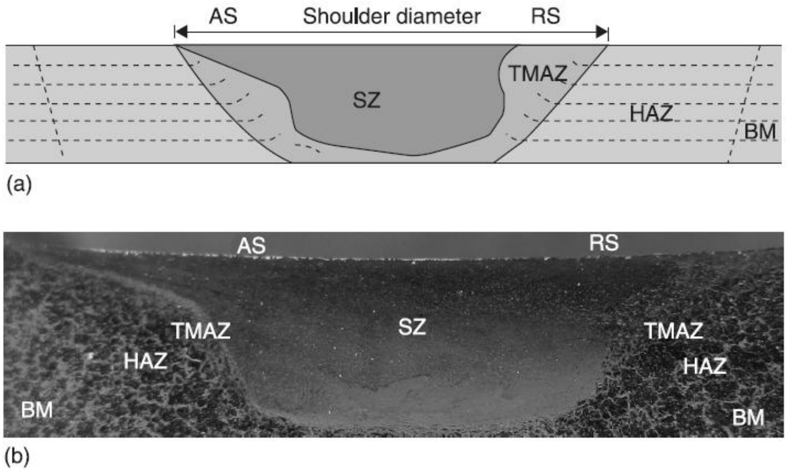

Figure 2: Schematic of microscopic zones in FSW

The FSW tool and heat generated from the friction deformed base material which changes its properties as well as microstructure size which produce a different grain boundary. In aluminium alloys when crystallization of the material does not occurthen, plastic strain generated in thermo-mechanical affected zone. The central zone which intermixes the two plastically deformed edges of two base material plates is called stirred zone or nugget zone. The area swept by the tool pin indicates the boundary of nugget zone (NZ). In this zone, the crushing, stirring and forging action of the FSW tool produces a weld with a finer microstructure than the parent material due to this fact the hardness of this zone is comparatively higher than another zone as well as base material. The interface of the nugget zone is smooth and diffused in advancing side, but it is sharp and small on the retreating side. In some of the aluminiumcases, the welding strength of the nugget zone is higher than the base material(Liu, Fujii, Maeda, & Nogi, 2003; Starink, Deschamps, Wang, & Kingdom, 2008).

3. Advantages of FSW

The solid-state FSW process produced a very high-quality welding joint and it is also very flexible in a variation of the parameters and materials. From the literature analysisit has following merits over other welding processes:

- FSW a type of solid-state welding, therefore, aluminium is welded very efficiently which is very difficult to weld with other joining processes;
- Excellent welding properties as compared to other joining processes;
- Absence of common welding defects like porosity, cracks, blow holes etc.;
- Environmental friendly joining process due to the absence of toxic fumes or gas;
- Welding preparation required is very less as compared to other conventional joining processes;
- Energy efficient due to the solid-state welding process no need of melting temperature;
- It keeps the base material properties in the welding area also despite the joining of the materials;
- Easily setup for the friction stir welding on simple milling machines resulting in lower set-up cost and training cost;
- Non-consumables, a tool can weld hundred meters long aluminium alloy;
- It can be easily operated in any position horizontal or vertical as there is no weld pool or melting of material;
- FSW reduced distortion and shrinkage in the base material;
- Workplace friendly due to absence of spatters and ultraviolet radiations;

- FSW generally give good appearance which needs minimum machining after welding process

4. Applications

In twenty-five years short time span friction stir welding complete many milestones in an automobile, marine, aerospace and many more industries. Firstly friction stir welding has been used for aluminium welding, but after the recent 10 years, intensive research makes it compatible with other hard metals, alloys, composites, and plastics also. Some of the important applications are as follows:

- Aerospace industry
- Construction industry
- Shipbuilding and marine industries
- Railway industry
- Land transportation
- Electrical industry and other industry sectors for thecomparatively small use of FSW.

5. Conclusions

The process has been an excellent substitute for alloys that have inherent fusion welding problems or other conventional joining processes. With the rapid research growth in *FSW*, which was patented not so long ago that considerable effort is being made in transferring the technological benefits from soft materials like aluminium to other materials. Efforts are on to make the process more flexible. In the new millennium, there is no doubt that the automotive sector will find an increasing number of uses for this process as its cost effectiveness and ability to weld dissimilar material combinations with minimal distortion is more widely appreciated.

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