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FRICTION STIR WELDING ON DISSIMILAR ALLOYS - A CRITICAL REVIEW

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ABSTRACT

This paper aims at studying Friction Stir Welding (FSW) which is a new technique in welding invented in 1991 by The Welding Institute (TWI). The process uses a rotating tool, which is non consumable to produce frictional heat as well as plastic deformation at the welding area. This method is used in high strength aluminium alloy aerospace components and high temperature alloy metals which are hard to join by traditional fusion welding method. This paper addresses the current status of friction stir welding. The working principle of this process, microstructure characterization, welding parameters, mechanical properties and application area of FSW for improved welding is discussed.

Key words: Friction Stir welding, Mechanical Properties, Microstructure

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1. INTRODUCTION

Friction stir welding (FSW), recently developed new technique introduced by Thomas and his co-workers at The Welding Institute (TWI) in 1991[1]. In this process two different materials are joined by frictional heat produced by rotating the tool which is non-consumable without melting of tool and work piece. (FSP), Friction Stir Processing, the process developed from FSW used to change the properties of metal. FSP was developed by Mishra and his colleagues [2] based on the principle of FSW. The working principle of FSW is very simple. As shown schematically in figure1, the rotating tool which comprises of a pin and shoulder and it moves along the joint to be weld and stir the material. The results in the formation of sound bond between the materials. The frictional heat generated between the work piece and rotating tool plastically soften the material without melting. The obtained fine micro structured joint gives good mechanical properties.

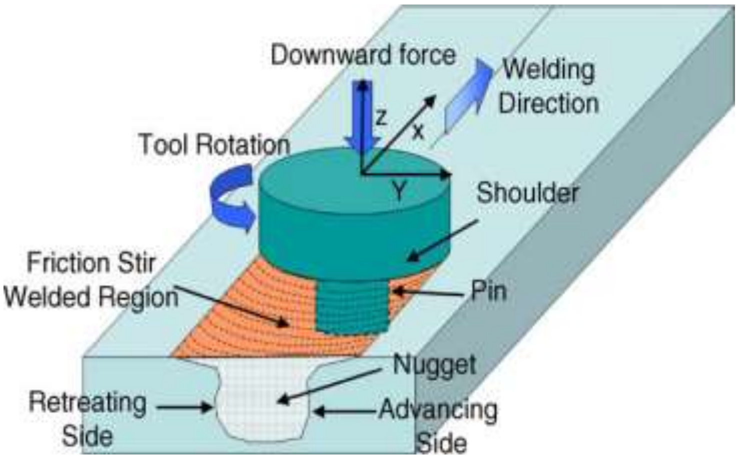

Figure 1: Schematic illustration of FSW [28]

In FSW, Advancing side (AS) is the side at which the direction of rotation and the welding directions are same, whereas retreating side (RS) indicates the side at which direction of rotation is reverse to the direction of welding. During FSW material flow from AS to RS around the rotating tool is a complex pattern. In aerospace and automotive industries FSW/FSP plays a major role due to reduction in weight and cost savings along with the approving maintenance of properties. This process can be used in various forms of welds like spot joint, lap, T, butt, corner, fillet, along with the hollow objects like tanks, pipes and tubes. In certain dissimilar Friction Stir Welding, the formation of brittle intermetallic compounds results in poor mechanical properties. Eg: Aluminium and Magnesium. Initially this joining process was applied in Al alloys such as 2xxx or 7xxx alloys which are difficult to weld by established fusion welding methods. Later its use was extended to magnesium, copper, nickel, titanium alloys and even steels, composites, [5] polymers, [6] and it is now widely used for dissimilar materials.

2. LITERATURE REVIEW

The industries like aerospace, nuclear, automobiles...etc. used various materials and different types of conventional welding processes are available for joining it. But this conventional welding process has so many problems in connection with melting and solidification such as high residual stress, large distortion, brittle cast structure etc. FSW can eliminate these problems absolutely and so it is known as ‘Green Technology’ as it does not produce any health problems and environmental issues. It can be deployed to different joints such as butt joint, lap joint, T joint, fillet joint etc. No need to clean the metal surface also. But the initial cost of this welding is very high and is less flexible than other conventional welding process.

2.2. Microstructure Characterization

Three different zones like i) Stirred (Nugget) Zone, ii) Thermo-Mechanically Affected Zone (TMAZ), and iii) Heat-Affected Zone (HAZ), have been identified based on microstructure of the material grains and precipitates as shown in figure 2.

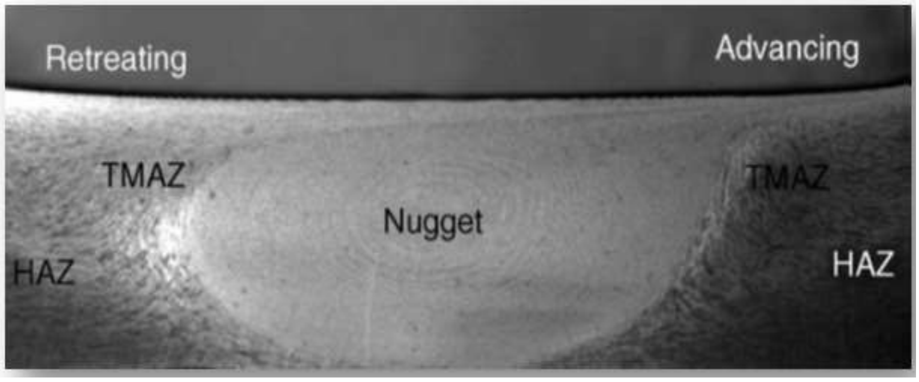

Figure 2. Various microstructural zones in FSW [28]

2.1.1. Stirred Zone

During FSW/FSP, due to extreme plastic deformation and frictional heating, a fine-grained microstructure which is recrystallized is generated in the stirred zone. This region is also known as nugget zone / dynamically recrystallized zone (DXZ). In some FSW/FSP situations, onion ring shape was formed in the nugget zone. Usually there is low dislocation density [9-10] in the core of the recrystallized grains. However, some researchers reported that the small recrystallized grains of the nugget zone include high density of sub-boundaries [11], subgrains [12], and dislocations [13]. The parent metal and the nugget zone interface is moderately diffused on the retreating side of the tool, but relatively pointed on the leading side of the tool [14]. The processing parameter, temperature of work piece, thermal conductivity of the material, and tool geometry are very much influence with the shape of the nugget zone. Normally, nugget zone can be classified as basin-shaped nugget and elliptical nugget. Sato et al. [15] explained the structure of basin-shaped nugget on friction stir welding of 6063Al-T5 plate.

2.1.2. Thermo-Mechanically Affected Zone (TMAZ)

The thermo-mechanically affected zone (TMAZ) occurs on either side of the stir zone. In this zone the effect of welding on microstructure is relatively smaller [9,16,17]. The TMAZ is depicted by an extremely deformed structure. During FSW/FSP the TMAZ experiences both temperature and deformation. Recrystallization does not occur in this zone due to inadequate deformation strain but dissolution of some precipitates takes place. Furthermore, it was discovered that the grains in the TMAZ frequently include an elevated density of sub-boundaries. A distinctive micrograph of TMAZ is shown in figure 3.

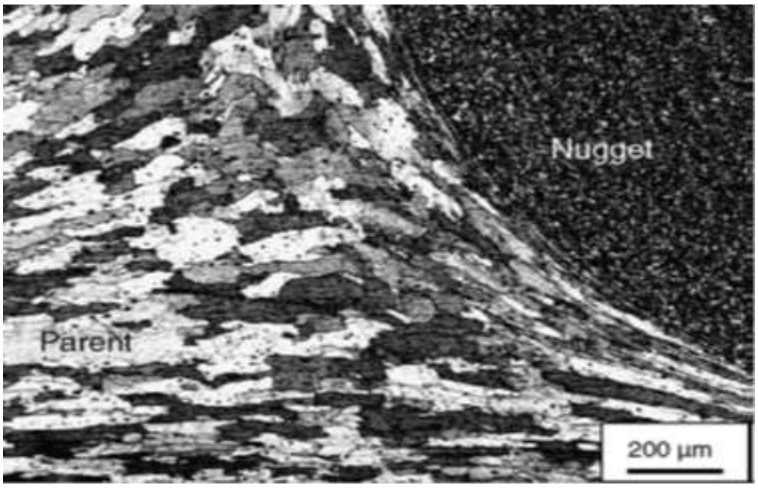

Figure 3. Microstructure of thermo-mechanically affected zone in FSP [16].

2.1.3. Heat Affected Zone (HAZ)

Next zone is heat-affected zone (HAZ), which is beyond the TMAZ and is very common in welding process. This zone does not surpass any plastic disfigurement but it experiences a thermal cycle (Fig. 4). Mahoney et al. [18] distinct that, for a heat-treatable aluminium alloy, the HAZ has a temperature rise above 250 ^{0}C. In HAZ the grain structure remains constant as in the parent material. However, the temperature above 250 ^{0}C exerts a considerable effect on the precipitate formation. Su et al. [19] have done a similar study in a detailed TEM investigation on FSW 7050Al-T651 (Fig. 4b). The magnitude of property change depends mainly on the base material, filler metal used and concentration of heat input into the metal while welding. Thermal diffusivity of the base metal plays the major role in HAZ. If thermal diffusivity is high the cooling rate of the material is high and HAZ is relatively small.

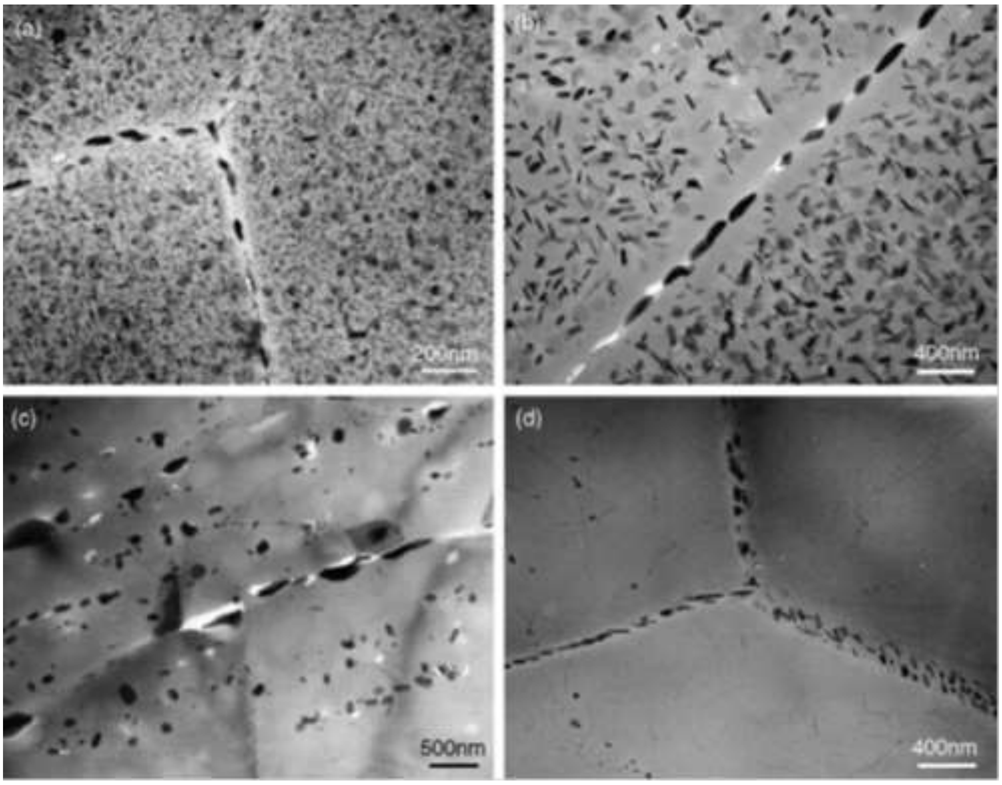

Figure 4. Precipitate microstructures in: (a) base metal, (b) HAZ, (c) TMAZ near HAZ, and (d) TMAZ near nugget zone (FSW 7050Al-T651, tool rotation rate: 350 rpm, traverse speed: 15 mm/min) [19].

2.2. Welding Parameters

When using FSW as a metal joining process, lots of welding parameters is to be considered. It is very important to analyse these parameters for the right application of this joining process. The correlation between the processing parameters, plastic deformation produced, heat generated and the resulting microstructure and mechanical properties were investigated. Increasing the tool rotation speed or shoulder diameter or decreasing the welding speed results in an increase in heat generation and then promoted grain growth. However, extreme heat generation needs to be avoided to safeguard the founding of coarse precipitates [21-22] or a brittle intermetallic compound which results in weak mechanical properties of the welds.

2.2.1. Effect of Tool Speed

FSW is a slower metal joining process than other process like arc welding, laser welding etc. The tool comprises of a shoulder and a pin. The cylindrical tool should rotate to produce the heat on the joint by friction and transverse through the joint to complete the weld. Both the shoulder and pin geometry influence the features of the contrasting weld. Microstructure is defined as the structure of an equipped surface of material as shown by a microscope above 25x magnification [7]. Different samples are shown in Fig. 5

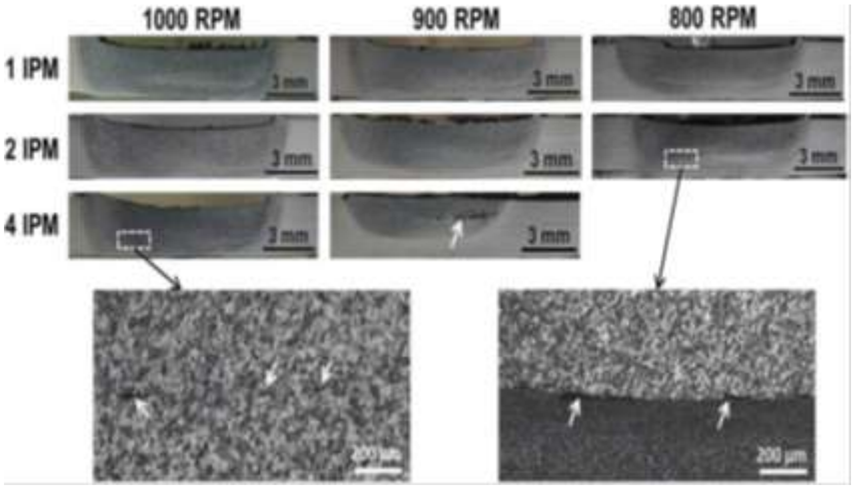

Figure 5. Micrographs of contrasting combinations of tool turning speed (RPM) and tool traverse speed (IPM). Note that white arrows shows the processing defects [8]

Above figure explains the micro structure changes in different combination of tool turning speed and traverse speed Making the traverse speed constant at 1 IPM with different RPM combinations (ie 1000, 900, and 800 RPM) were analysed. When it works at 1IPM the stir zones are evidently visible and a defect free processed zone is generated. At the range of 2 IPM the fault can only be visible at 800 RPM. Further traverse speed increased to 4 IPM, minute cavities are formed at 1000 RPM as in figure 5. In the processing condition 4IPM / 900 RPM, insufficient heat is generated due to faster travel speed of the tool which results in lack of penetration and defacement of the tool tip [8].

Tool tilt and plunge depth have major effect in friction stir welding. A common series for tool tilt is among 2 and 4 degrees, in such a way that the tool leans into the joint. Though a very minor tilt, it helps the tool to easily move across the joint line because less pressure is put in the direction of the joint line. The plunge depth is the depth to which the shoulder of the tool sinks into the material.

2.3. Mechanical Properties of Dissimilar Welds

2.3.1. Micro-hardness

Microstructure of welded alloys and the processing parameters are closely related to the hardness of the weld. Figure 6 shows the abration profile of the cross section of a 2024-T3/7075-T6 weld. [23] There is a fluctuation in the hardness values at the nugget zone. It is caused by the onion ring structure arrangement with alternating bands of both alloys. In the stir zone, the microhardness values are almost constant and decreases near to thermomechanically affected zone (TMAZ) including heat affected zone (HAZ). The grain sizes of TMAZ are bigger than the grain size of stir zone. Consequently, the microhardness values of TMAZ are found lower than the stir zone.

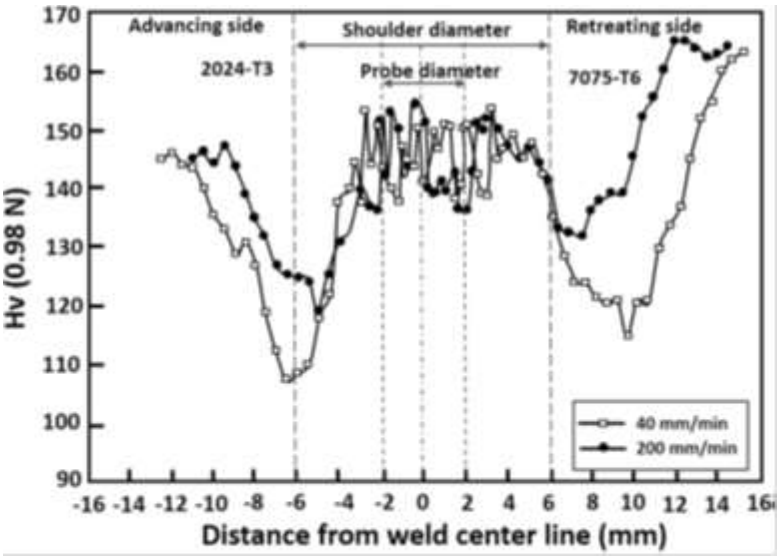

Figure 6 Micro-hardness details of AA2024/AA7075. [24]

2.3.2. Tensile properties

Tensile test is a fundamental mechanical test used in materials to determine material properties. In different number of materials we can use the Friction Stir Welding. Initially the research and industrial interest focus on Al alloys. Defect free weld with high quality mechanical properties have been made in Al alloys and weld can be used in any position [25-26]. The stress-strain patterns of friction stir processing Al-4Mg-1Zr as shown in figure 7. The ideal strain rate for supreme elongation at 525^{0}C was $1x10^{-1}s^{-1}$. This shows that towering strain super plasticity can be accomplished in the Al-4Mg-1Zr alloy by FSP.[27]

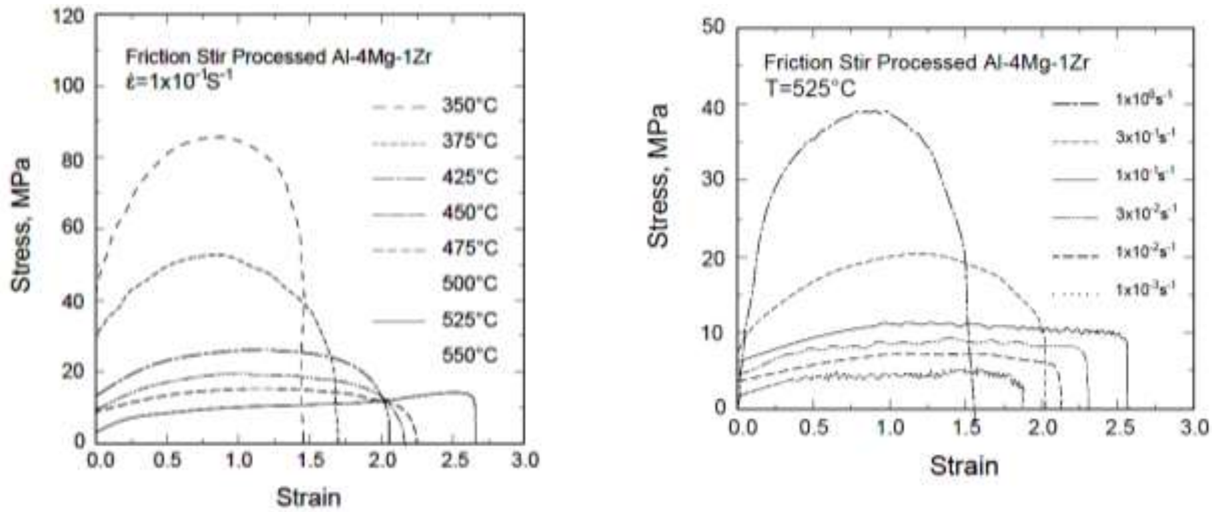

Figure 7. Stress strain properties of friction stir processing Al-4Mg-1Zr, (a) initial strain rate at 525^{0}C, (b) temperature at an initial strain rate 1x10-1 s-1[27]

2.4. Applications of FSW

Friction Stir Welding (FSW) is an advanced welding technique patented by TWI in 1991. Now it is a common technique used for many worldwide applications mostly in the fabrication of Aluminium components and panels. Initially FSW was commercially used by two Scandinavian aluminium extrusion companies in the manufacturing of fish freezer panels, as well as deck panels and helicopter landing platforms. In railway, FSW is used for the production of prefabricated aluminium panels. The aerospace industry is extensively used FSW, for the manufacturing of large tanks used in satellite launch vehicles using high strength aluminium alloy. Now –a-days several industries used Friction Stir Welding for the manufacturing of light weight aluminium frame structure for business-related and armed aircraft. Automotive Industry is also uses the same technology for the production of alloy wheels and fuel tanks. Facade panels and cathode sheets are friction stir welded at 'AMAG' and 'Hammerer Aluminium Industries', including friction stir lap welds of copper to aluminium. 'Apple' used friction stir welding in 'iMac' to join effectively the bottom to the back of the device in 2012.

3. CONCLUSIONS

FSW technology was devised at The Welding Institute (Cambridge, UK) in 1991; quite a few successful industrial applications of FSW have been indicated. FSW is a solid state welding, which is used where the conventional fusion welding failed. The formation of brittle intermetallic compounds leads to poor mechanical properties. Based on micro structural characterization, three distinct zones are identified. Different Welding parameters such as tool rotation, transverse speed and axial force have a significant effect on the amount of heat generated and strength of FSW joints.

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