International Journal of Advance Research in Science and Engineering
Vol. No.5, Issue No. 10 , October 2016
www.ijarse.com

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

A REVIEW ON FRICTION STIR WELDING OF HIGH STRENGTH 7XXX ALUMINIUM ALLOYS

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ABSTRACT

The objective of this paper is to present a review on various aspects of friction stir welding, with particular emphasis on FSW of7XXX aluminium alloy series. The fundamental principles, thejoining mechanism, heat generation during the process, microstructural features and the effect of process parameters on the mechanical properties of the joints and susceptibility to stress corrosion in the joints are reviewed. The review shows that there is a general trend of the mechanical properties in accordance with variation in the experimental values of the process parameters.FSW is considered to be the most important development in metal joining in recent years and is a''green'' technology due to its versatility, energy efficiency and environment friendliness. In comparison to the conventional welding methods, FSW consumes considerably less amount of energy. Noflux orshielding gas is used, thus making it environmental friendly. The joining does not require any use of filler material and therefore any aluminium alloy can be easily joined without having any concern for the compatibility of composition, which is an issue in fusion welding. Moreover dissimilar aluminium alloys and composites can be joined with equal ease. Thus this process can be considered as a lean, mean and green process.

Keywords- *Friction stirwelding, Tool design, rotational speed, tensile strength, aluminium alloys.*

I. INTRODUCTION

The difficulty of making high-strength, fracture and fatigue resistant welds in aerospace aluminium alloys, such as highly alloyed 7XXX series, has inhibited the fuller use of welding for joining aerospace structures for long. These aluminium alloys are generally segregated as non-weldable because of the lower quality of solidified microstructure and porosity in the fusion zone [1]. Also, they own inferior mechanical properties in comparison to the base material. These factors make the joining of these alloys by fusion welding processes unattractive. Some aluminium alloys can be welded by resistance welding, but the surface preparation is expensive, because surface oxide causes a major problem. Friction stir welding (FSW) is a solid state continuous hot shear welding process with unchallenged similarities to electron beam, laser, and plasma arc welding in the way that FSW has

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

a moving point welding source with keyhole at the end of the joint[2]. Particularly, it can be used to join high-strengthaluminium alloys and other metallic alloys which are hard to weld by conventional fusion welding.

II. DEVELOPEMENT OF FRICTION STIR WELDING

The Welding Institute (TWI) in the UK had for years engaged in various research and development and industrial activities related to friction welding. Wayne Thomas and his colleagues in TWI had worked long to develop several variants of friction welding. In particular they developed friction extrusion, third body friction joining processes and friction hydro-pillar processing. Over the long period of research on these new processes, the researchers in TWI studied and observed number of important phenomena and amass an in-depth working knowledge of those processes. These include highly plasticized third-body effect and the transportation of the plasticized material, the adiabatic heating on deformation, and the relationship between torque androtation speedwhen a sufficient amount of plasticized material is present during processing. Eventually in 1991 Wayne Thomas et. al. in TWI patented a novel method of solid state joining of aluminium and its alloys [3].

III. PRINCIPLE MECHANISIM OF FRICTION STIR WELDING

Friction stir welding (FSW) is a solid-state fabrication technique in which coalescence occurs due to thermo-mechanical deformation of plates to be welded, since the resulting temperature exceeds the solidus temperature of the plates. The basic concept of FSW technique is depicted in Figure 1. The tool in FSW is non-consumable rotating tool having a distinctly designed probe and shoulder. Tool pin is plunged into the faying faces of sheets or plates to be joined, and then it moves in the transverse direction along the length. The tool rotates in the clockwise direction and translates from front to back as shown in Figure 1. The side, where direction of tool rotation and tool travel issame is termed as advancing side which is opposite to the direction of metal flow. The opposite side to advancing side where direction of tool travel and tool rotation is opposite, is termedas retreating side. Due to frictional heat between tool and workpiece, material around the pin gets softened and a solid state joint is produced without melting [4,5,6,7].

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

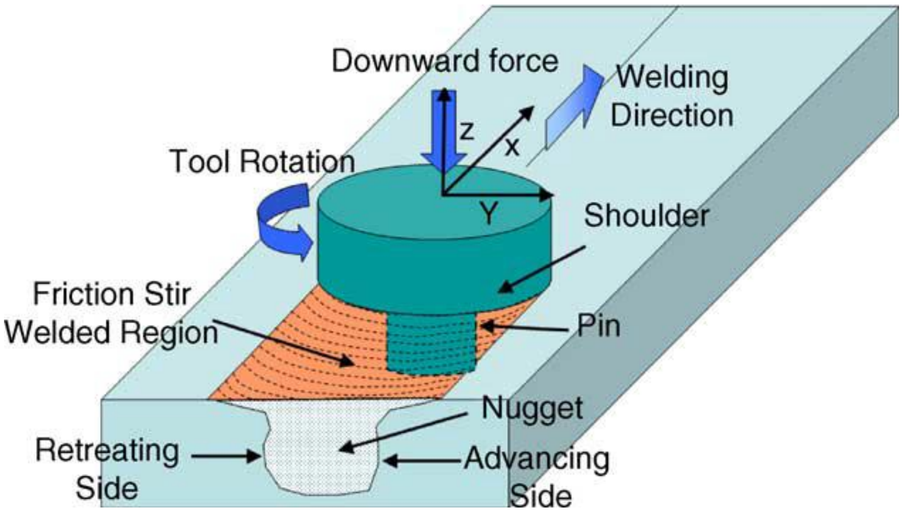

Fig.1Principle mechanism of friction stir welding [1].

IV. MICROSTRUCTURAL FEATURES OF FSW WELD

In FSW joints generally four microstructural regions exist as illustrated in Figure 2. The regions are (a) nugget zone (b) thermo-mechanically affected zone, (c) heat affected zone, (d) base metal. The zonein which tool pin rotates and produces frictional heat results in severe plastic deformation is callednugget zone or stir zone or fully recrystallized zone. The thermo-mechanically affected zone (TMAZ) is very near to weld nugget and it is plastically deformed by action of tool. In this region material deforms without recrystallization. The heat-affected zone (HAZ) that is in between TMAZ and base metal is affected by heat but no plastic deformation occurs in this region, however mechanical and microstructural properties vary. The base metal region is unaffected by the heat since it is far away from the recrystallized zone and therefore microstructural and mechanical properties of this region remain unaltered [5].

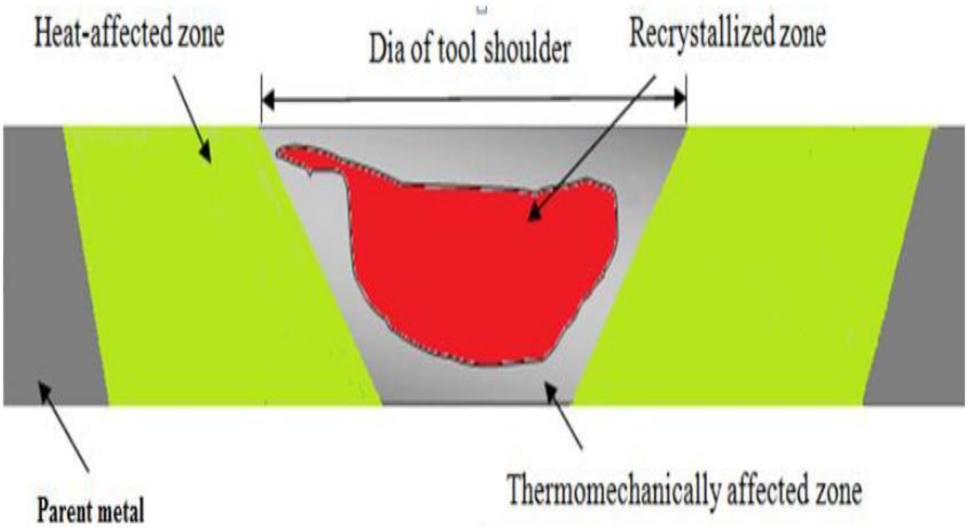

Fig.2Microstructural regions of friction stir weld.

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

V. PROCESS PARAMETERS IN FRICTION STIR WELDING

There is relatively less number of variables in fsw in comparison to fusion welding. The main independent variables that control quality of joint produced are:

5.1 Tool Rotation

For FSW tool rotation rate in clockwise or counter clockwise direction are important parameters. The motion of the tool generates frictional heat within the workpieces, extruding the softened plasticized material around pin and forging the same in place so as to form a solid state joint. Higher tool rotation rates generate higher temperature because of higher frictional heating and result in more intense stirring and mixing of material.

5.2 Transverse Speed

Higher transverse speeds lead to weaker stirring effect of the welding tool which causes occurrence of weld defect. On increasing the transverse speed, contribution of plastic deformation to the temperature rise increases. However, the variation of the transverse speed does not affect the power needed for FSW much.

5.3 Tool Tilt Angle

In addition to the tool rotation rate and traverse speed, another important process parameter is the angle of tool tilt with respect to the workpiece surface. An optimum tilt of the spindle towards trailing direction ensures that, the shoulder of the tool holds the stirred material by threaded pin and move material efficiently from the front to the back of the pin. The tool is usually characterized by a small tilt angle, as it is inserted into the sheets blank material undergoes a local backward extrusion process up to the tool shoulder. Further, the plunge depth of pin into the work pieces (also called target depth) is important for producing sound welds with smooth tool shoulders [1].

5.4 Tool Design

The torque requires during welding determine various tool shoulder diameters. As the shoulder diameter increases, sticking torque increases, reaches a maximum and then decreases. The examination of this behaviour shows that two main factors affect the value of the sticking torque. One is the strength of material that decreases on increasing temperature, due to an increase in the shoulder diameter. Other is the area over which the torque is appliedwhich increases with shoulder diameter [8].

VI. PARAMETRIC STUDY OF FSW OF AL 7XXX ALLOYS

The aircraft aluminium alloys generally present low weldability by traditional fusion welding process and thus fsw presents more optimistic opportunities to overcome this limitation of the alloys. **S. Rajakumaret. al**. studied the influence of process and tool parameters on tensile strength properties of AA7075-T6 joints produced by friction stir welding. Square butt joints were fabricated by varying process parameters and tool parameters. In this investigation it is found that the joint fabricated at a tool rotational speed of 1400 rpm, axial force of 8 kN ,welding speed of 60 mm/min, , using the tool with 15 mm shoulder diameter, 5 mm pin diameter, 45 HRc tool hardness yielded higher strength properties compared to other joints[9].

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Muhsin J. J et. al.has made three-dimensional nonlinear thermal numerical simulations are for the friction stir welding (FSW) of AA 7020-T53. Three welding cases with tool (rotational and travel) speeds of 900rpm; 40mm/min, 1400rpm;16mm/minand 1400rpm;40mm/min are analysed with an objective to study the variation in transient temperature in workpiece of 5mm thickness. It has been observed that the temperature distribution in the FSW process is symmetric with respect to thewelding line. Increasing travel speed lead to decreasing transient temperature distribution and on increasing rotational speed temperature distribution increases. Experimental data illustrates that peak temperatures are higher on the advancing side than theretreating side [10].

K.Kumar et.al investigated the role of axial load on weld formation and the optimal axial load for producing defect free welds was found out. Generally in friction stir welding the tool is plunged at the interface of the materials in a way that the tool axis and interface were aligned. Besides this, the axial load was varied by linearly between the base material and tool. This was done by keeping the backing plate at an angle to the tool axis in the welding direction. The base material used in this study was7020-T6, which was artificially aged to peak hardness. The defect free aluminium alloy 7020-T6 joint was made by continuously increasing the axial load. The optimal axial load was seen to be 8.1kN. Moreover, the highest strength of weld produced by varying axial load was 340Mpa which was 84% of the base material strength and with ductility of 7.3% at 8.8kN. The secure tool deviation from the interface was 1mm in the advancing side and 1.6mm in the retreating side of a frustum shaped tool. The tensile strength decreases sharply when the tool deviated from the secure range [11].

DongJihonget. al experimented Friction stir welding of 7A60 aluminium plate of 6 mm thickness in a single pass welding. The experiment results demonstrate that the welding tool figuration affectedtensile strength.When the welding speed is 200 mm /min and the rotating speed is 300 rpm, the weld achieved is of good quality,and the tensile strength of the joint reaches 488.7 MPa, about 75% of the ultimate strength of the base metal alloy with higher welding efficiency. The fracture mode is mixed ductile and brittle fracture. Incomparision to base metal, the microstructures in the nugget contains fined, equiaxedgrains[12].

Lombard et al., (2008) in there research work present a systematic approach to optimizing FSW process parameters (tool rotational speed and feed rate). Eleven experiments were performed by varying the tool rotational speed and welding speed. The tensile strength of the joint increased from 289 to 313 MPa by varying the tool rotational speed from 400 rpm to 200 rpm at the fixed welding speed of 85 mm/min. The tensile strength of the joint increased from 254 MPa to 315 MPa by varying the rotational speed from 635 rpm to 254 rpm at the fixed welding speed 135 mm/min. The work shows that the tool rotational speed is the key parameter governing the tensile strength.

G. Buffaet. al.observed that residual stresses in FSW processes are due to both thermal andmechanical causes. The former are due to the friction forces work and to the deformation work both converted into heat. The latter are strictly connected to the strong gradients of strain and strain rates occurring due to the tool pin action on the material to be welded, which further determine relevant microstructure changes in the parent material but show low effect in the residual stresses produced[13].

Kaustubh s gaikwadet. al. studied Friction Stir Welding on T-Joint using tool as Molybdenum and work piece material as AA7050.The speed of tool (pin and shoulder type), has been taken as 650 rpm, 700 rpm & 740 rpm and its translational speed as 4.23 mm/s. The temperature of the work piece plates is to be 20ºC. It has been found out that as tool rpm goes on increasing the flow stress decreases, the temperature distribution increases and the viscosity remains unchanged for 650 rpm and 700 rpm and 740 rpm.This study will show the temperature distribution, the stress distribution and the viscosity flow in the work piece plates at the give parameters at specified boundary condition. [14].

G. Venkateswarluet. al. Investigated on output variables, such as peak temperature and flow stress of friction stir welding of aluminium alloy AA7075. The process parameters considered in this investigation were rotational speed, traverse speed and shoulder diameter. The results indicate that the FSW process parameters greatly influence the temperature distribution and flow stress during the process. It is found that peak temperature increases and flow stress decreases with increase of rotational speed with varying traverse speed and also found that the peak temperature decreases and flow stress increases with increase of traverse speed with varying rotational speeds. The temperature and flow stress distribution increase with increase of tool shoulder diameter[15].7xxx series alloys can provide superior ballistic protection under all modes of attack when compared to other aluminium alloys, and can be superior to steel armour on a weight for weight basis. Despite these attractive properties the weldable 7xxx alloy are not widely used for structural applications due to the susceptibility to the stress corrosion cracking of these alloys.

VII. CONCLUSIONS

Aluminium alloys in which zinc and magnesium are the main alloying additions (*7xxx* series) are conspicuous amongst the commercial aluminium alloys because of their ability to be age hardened to strengths well in excess of the strengths that can be produced in any other aluminium alloys. Friction stir welding is a practical solution to join these high strength alloys. From the above study it can be concluded that sincewelding speed of the tool, rotational speed of the tool and the axial force greatly effect heat generation and temperature distribution along the weld line,they are the important parameters to decide the quality of joint being produced. Thus this paper reveals scope to weld high strength 7XXX series aluminium alloys by FSW with optimization of process parameters to obtain high quality joint.

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