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Friction Stir Welding of Aluminium Alloy and Stainless Steel and Analysis of Mechanical Properties

Patel Pratikkumar R[1], Suthar Ghanshyam B[2], Ray Urvesh J[3], Shukla Jyotish[4], Mr. Barot Jaydeep[5]

[1-4]Mechanical Department, Gujarat Technological University/Sigma institute of engineering, Vadodara, Gujarat, India
[5]Assistant Professor, Mechanical Department, Sigma Institute of Engineering, Vadodara, Gujarat, India

ABSTRACT

Friction stir welding is the solid state joining process which can produce high quality welds with either similar or dissimilar materials and has been attracting increasing attention. It is used to join the high strength alloys which are difficult or uneconomical to weld by conventional fusion welding techniques. Friction stir welding was invented and established by The Welding Institute (TWI) in 1991.The aim of this paper is to reviews the work done in the area of joining aluminium alloy and stainless steel, analysis of mechanical properties of weld and concludes by suggesting further scope for research in Friction stir welding and optimum process parameters.
Keywords: Friction, Stir, Welding, Analysis, Properties

I. INTRODUCTION

FSW is a solid–state joining process in which a rotating tool with a shoulder moves along the corner surfaces of two rigidly clamped plates placed on a backing plate.

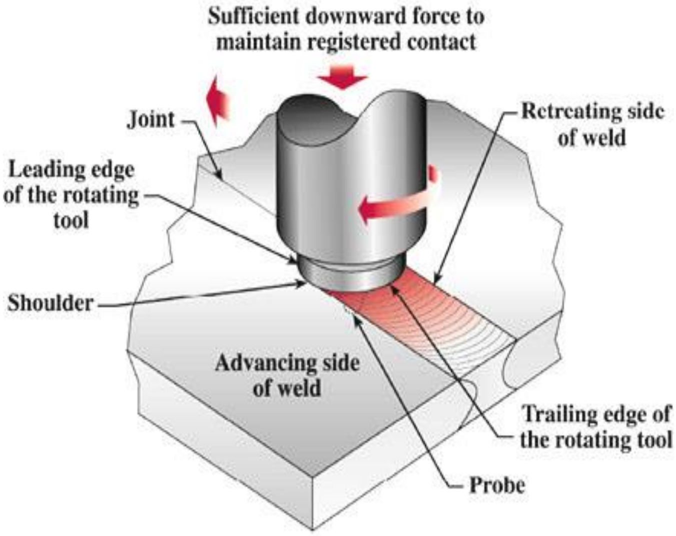
FRICTION STIR WELDING was invented by The Welding Institute (TWI) of Cambridge, England. In the FSW process, a rotating tool containing a pin and a shoulder is plunged into the joint between two work pieces, generating heat by friction. Once the heat has built up to the desired level, the tool is translated along the joint. Plasticized base material passes around the tool, where it is consolidated due to force applied by the shoulder of the tool. [1]

Friction stir welding has been applied to metals with moderate melting points. Initially, FSW was applied primarily to aluminium alloys, which could be easily welded due to the relatively low softening temperatures of these alloys. Other relatively soft metals, such as copper, lead, zinc, and magnesium, have also been welded. In contrast, for a number of years it was difficult to weld ferrous alloys and other high- softening-temperature metals due to the lack of suitable tool materials.

In FSW there are two important factors, tool rotating (in rpm) and travel speed (in mm/min).It is very obvious that high and low speed would cause problems in joining the material. For instance, high speed would cause lack of penetration and also lack of material aggregation, on the other hand too hot processing conditions can cause flash formation or nugget collapse. While, under too cold condition insufficient flowing or lack of fill would occur on the advancing side [2].In general, because the heat generated would create by the friction between the tool and base metal, speed of the tool and finally welding speed is very important to consider. Many scholars did their researches on thermal issues and heat generation on the stainless steels that their results can be effective in this process. According to findings in Reynolds et al. [3], residual stress of 304L stainless steel in FSW, are the same in character and magnitude with fusion welding. Furthermore, lower energy input due to lower tool rotation would conclude to lower weld temperature and a fine weld nugget grain size. Cho et al. [4], examined FSW on 409 stainless steel that is kind of ferritic by Polycrystalline Cubic Boron Nitride (PCBN) tool, they found that fine grain microstructure was settled by dynamic recrystallization because of high heat generation and shear deformation. Jata, Semiatin. [5], Heitz and Skrotzki[6] have proposed that stainless steels type 304 and 304L have lower stacking fault energy. Sato et al. [7] have examined recrystallization in type 304L and found that the first is dynamic recrystallization during intense deformation that in conclusion disparate distribution of dislocation density is achieved within structure

WORKING PRINCIPLE:

A rotate with constant speed non-consumable cylindrical-shouldered tool with a profiled probe is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material. The pin is slightly shorter than the weld depth required, with the tool shoulder riding at top of the work surface. Frictional heat is generated between the wear resistant welding components and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the pin is moved forward, a special profile on its leading face forces plasticised material to the rear where clamping force assists in a forged consolidation of the weld. This process of the tool traversing along the weld line in a plasticised tubular shaft of metal results in severe solid state deformation involving dynamic re-crystallization of the base material. [1] [8]



Friction stir welding principle [8]

The main FSW process parameters are the following[9][10]:

- **Tool shoulder**: It is a part of the tool that is rotates in contact with the surface of the work piece.

- **Tool pin**: tool pin is a part which penetrates the work piece surface.

- **Advancing side**: advancing side of weldis same as the direction of rotating of the shoulder.

-**Retreating side**: retreating side of weld isopposite to the direction of rotation of the shoulder.

- **Down or axial force**: It is a force applied to the FSW tool, to plunge the probe into the work piece and maintain contact with the surface of the work piece (kN).

-**Traverse force**: It is a force required to translate the rotating FSW tool, to plunge the probe into the along the joint (kN).

-**Tool rotation speed**: It is a speed of the tool. This can be mentioned as rotation speed (rev/min), peripheral velocity (m/s), or angular velocity (rad/sec).

-**Traverse Speed**: It is a speed at which the rotating tool is translated along the line (mm/min).

-**Spindle torque**: Spindle torque required to rotate the FSW tool when plunging into work piece and traversing through the work- piece along the joint (Nm).

-**Tool tilt angle:** The angle at which the FSW tool is place relative to the work--piece surface, i.e. zero tilt tools are place perpendicular to the work-piece surface(degrees).

-**Tool plunge**: Tool plungeis a process of forcing the tool into the material at the start of the weld. Plunge rate is measured in mm/sec.

-**Anvil/backing bar**: Anvil/backing bar is a supporting member used to absorb the forces applied to the work piece and minimizing material distortion. A secondary function is to prevent plasticized material extruding from the underside of the joint.

-**Work piece/ material**: It is raw material/component where to be weld.

-**Weld nugget or stirred zone**: It is a central area of the thermos-mechanically affected zone (TMAZ) at which welding is occurred.

-**TMAZ**: TMAZ is lies between nugget zone and HAZ. It is area where the material affected by heat and mechanically deformation during welding.

-**HAZ**: It lies between TMAZ and unaffected area. The material affected by heat during welding.

-**Unaffected material**: It is a zone at which no heat or deformation affect during welding.

-**Pilot hole**: In some cases it is advisable to pre-drill a hole in the work-piece, into which the FSW tool can be plunged. This is particularly relevant when welding hard or thick section materials.

-**Exit hole**: A hole left at the end of the weld when the tool is withdrawn, resulting from the displacement of material during the tool plunge. Some special techniques are in use to fill or prevent the occurrence of this hole.

ADVANTAGES:

I. Good mechanical properties as in weld condition
II. Improved safety due to absence of toxic fumes
III. Easily automated on simple milling machines
IV. Can operate on all positions (vertical, horizontal) etc.
V. Low environment impact
VI. High superior weld strength
VII. No consumables.

DISADVANTAGES:

I. Work pieces must be rigidly clamped
II. Slower traverse rate than fusion welding
III. Exit hole left when tool is withdrawn.
IV. High investment
V. Need backing support
VI. Critical tolerance
VII. Less flexible

APPLICATIONS:

I. Aerospace
II. Ship building & offshore
III. Automotive

II. LITERATURE REVIEW

FSW is a thermo-mechanical phenomenon, there is much material motion and shear force and also the temperature will increase to below the melting point [11], [12].Friction Stir Welding is a process that is strongly influenced by heat generation and heat flow [13]. Contact between tool and work-piece due to rotating tool and travel along the weld can make friction that is cause of heat generation in FSW. Tool of welding as mentioned before consists of pin and shoulder that the surface of shoulder can generate majority of heat [11].

It is important that the flow, ductility and work hardening of 304L are affected by the strain rate [14]. According to prior studies friction stir welding on stainless steels type 304 and 304L have good recrystallized grain in stir zone. During the welding friction between the tool and work piece and also plastic deformation are cause of heat generation [15].

High speed rotating tool causes more heat due to friction. The point that should be considered is that for high melting material like as stainless steels in this process preheating is one of the factors for making suitable plastic area [16].

It is obvious that rotational and travelling speeds are main factors in heat generation and also heat input issues. The relation between speeds and heat input is complex during FSW. Too much or too low heat input affect the weld quality. If the heat input is too low, suitable plastic conditions prevented that causing voids during welding and in extreme cases the tool may break. On the other hand, with high heat input weld properties are excessively deteriorated. Generally, lower heat input in friction stir welding cause improve mechanical properties as well as decreased distortion and residual stress [17].

The surface finish of weld sample welded at higher rotational speed is better than lower one this confirms that as the tool rotation speed is having greater influence on surface finish at the weldment[18]. Friction stir welding on aluminium alloys is very useful for the design and building of aluminium ship structures[19].

The friction stir welding process used successfully to join dissimilar aluminium alloys. Better mechanical properties like hardness and tensile strength were obtain with the FSW plate fabricated with 900 rpm tool rotational speed and 100mm/min welding speed[20]. The mechanical properties of similar and dissimilar friction stir welded joints of aluminium and copper were evaluated at tool rotational speeds from 150 to 900 rpm in steps of 150rpm at 60mm/min travel speed[21]. The impact strength in friction stir welding is highly influenced by diameter than feed than speed. Impact strength is increasing with increasing speed[22]. In friction stir welding observed that the higher rotational speed, the normal load and spindle torque requirement decreased[23].

The shear strength of lap joint in friction stir welding is reduced by high increasing of the tool rotational speed or decreasing of the travel speed[24].

Base Material	Parameter	Range	Literature
Al 5052 and AL 6061	Speed	1120, 1400 rpm	[23]
	Feed	60,80,100 mm/min	
	Tool tilt angel	3°	
Al 6063	Speed	970,1200,1950 rpm	[22]
	Feed	30,40,50 mm/min	
	Tool tilt angel	-	
AA6351	Speed	150 to 900 rpm	[21]
	Feed	60 mm/min	
	Tool tilt angel	2°	
Al6061-T6	Speed	1000,1400 rpm	[18]
	Feed	-	
	Tool tilt angel	0°	
AA5052	Speed	680 rpm	[10]

and AA6063	Feed	-	
	Tool tilt angel	-	
Al 304	Speed	600 to 1180 rpm	[9]
	Feed	-	
	Tool tilt angel	1.5°	
Al5052 and SS304	Speed	1000rpm	[24]
	Feed	80mm/min	
	Tool tilt angel	1.5° to 2.5°	

III. RESULTS AND DISCUSSION

From study of number of research papers the results obtained by various researchers are different. The optimum parameters at which the optimum mechanical properties were founded are listed in the following table

Base Material	Tool Rotation Speed Range (in rpm)	Travel Speed (in mm/min)	Ultimate Tensile Strength (in MPa)	Wear Strength	Tool Tilt Angle (in degree)	Literature Referred
AA 7075-T651 and AA 6061-T651	900	100	205.23	-	-	[20]
Austenitic Stainless Steels	750	47.5	470	-	1.5	[25]
AA5052 and AA6061	2000	100	220	-	-	[23]

IV. CONCLUSION

The present review has been undertaken, with an objective of FSW of Al alloy to stainless Steel and to study the effect of mechanical properties and FSW parameters. Compared to the conventional fusion welding process, FSW is found to be a very useful and economical technique for joining Al alloy to steel because of the considerable improvement in ductility, strength, micro-hardness, fatigue and fracture toughness and also 80 to 85 % of yield stress of the base material has been achieved. Various studies have highlighted the effect of inter-metallic on the formation of the joint and its strength was found to reduce on formation of thick inter-metallic layer. FSW exhibits a higher fatigue life as compare to laser welding and MIG welding but lower than that of the base materials. Tool designs is very important factors for producing the sound and defect free weld and mostly cylindrical threaded pin and concave shoulder are widely used welding tool features. In the present review FSW process parameters such as tool rotational speed, welding speed, spindle tilt angle and tool type should be conduct for improving the ultimate tensile strength, micro-hardness and percentage elongation of FSW joint by choosing optimum weld parameters. Heat and material flow during FSW are important issues of concern so a wide research should be conducted on these two phenomena.

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