Solid State Friction Stir Welding Using Dove Tail Groove Butt Joint

Sulaiman, Sivaprakasam Thamizhmanii

***Abstract*— Welding of metals has become increasingly important in almost all manufacturing industries. Welding process can be mainly classified as fusion and solid state or non-fusion welding. In fusion welding, metals are involved in melting and forming the bond. One of the solid state welding is Friction Stir Welding (FSW) process dependent on heat generated by friction. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint. The material used in the FSW process is Aluminum 6061-T6 to Aluminum 6061-T6 by dovetail butt joint. In this research, dovetail groove is wire cut and joined by FSW. The parameters are used vertical rotation of the tool at 1050 and 1350 RPM, transverse speed of 200, 325,500, 600 and 725 mm with constant plunge depth of 0.50 mm.**

***Index Terms*— Dove tail groove joint, Fatigue strength, Friction Stir welding, Tensile strength**

I. Introduction

Friction stir welding is a new technique developed by The Welding Institute (TWI) for the joining of aluminum alloys [1]. Friction stir welding (FSW) is a new metal joining process that is presently attracting considerable interest. The process is solid state in nature and relies on a localized forging of the weld zone to produce the joint. In this welding process, a rotating welding tool is driven into the material at the interface of, for example, two adjoining plates, and then translated along the interface and shown in the figure 1. Friction stir welding offers ease of handling, precise external process control and high levels of repeatability, thus creating very homogeneous welds. No special preparation of the work piece is required and little waste or pollution is created during the welding process. Furthermore, its applicability to aluminium alloys, in particular dissimilar alloys or those considered unweldable by conventional welding techniques, such as Tungsten Inert Gas (TIG) welding, proposes it as an attractive method for the transportation sector. Friction heats the material which is then essentially extruded around the tool before being forged by the high down pressure. The weld is formed by the deformation of the material at temperatures below the melting temperature. The simultaneous rotational and translational motion of the welding tool during the welding process creates a characteristic asymmetry between the adjoining sides [2]. FSW process demonstrated to very little distortions and the generated residual stresses are proved to be particularly low, compared to the traditional welding processes [3–5]. The Friction stir welded material produces three different areas: the weld nugget, the thermo-mechanically affected zone and the external heat affected zone. Thermo-mechanical plasticized zone is produced by friction between the tool shoulder and the top plate surface and by contact of the neighbouring material with the tool edges, inducing plastic deformation [6]. Fig.1 shows the working principle of FSW [7]. FSW joints usually consist of four different regions as shown in Fig.2. They are: (a) unaffected base metal (b) heat affected zone (HAZ) (c) thermo-mechanically affected zone (TMAZ) and (d) friction stir processed (FSP) zone [8-9]. The formations of above regions are affected by the material flow behaviour under the action of a rotating non-consumable tool. However, the material flow behavior is predominantly influenced by the FSW tool profiles, FSW tool dimensions and FSW process parameters [8]. The tool pin and shoulder are helpful for heat generation, and material by stirring producing the joint. In this process no melting occurs and the heat is generated internally by means of friction between the material-tool interface and the plastic deformation takes place without pre or post heating [10].

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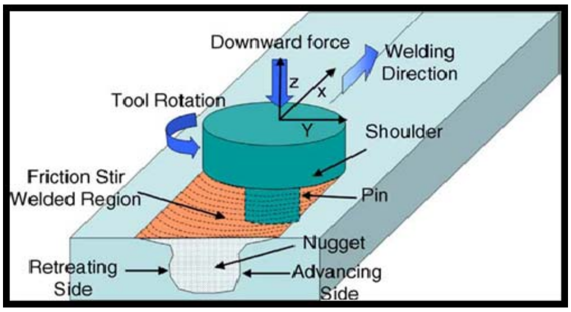

Fig.1. Principles working of FSW [7]

Table 1. Chemical properties

Alloy	Fe	Cu	Si	Zn	Mn	Mg	Cr	Ti	Al
%	0.16	0.15 -0.40	0.04-0.80	0.25 Max.	0.15 max	0.80-1.20	0.04-0.35	0.15 max	Bal.

Table 2. Mechanical properties

Ultimate Tensile Strength (UTS)	310 MPa
Yield strength	276 MPa
Fracture strength	96.5 MPa.
Elongation	12 %
Brinell hardness	95

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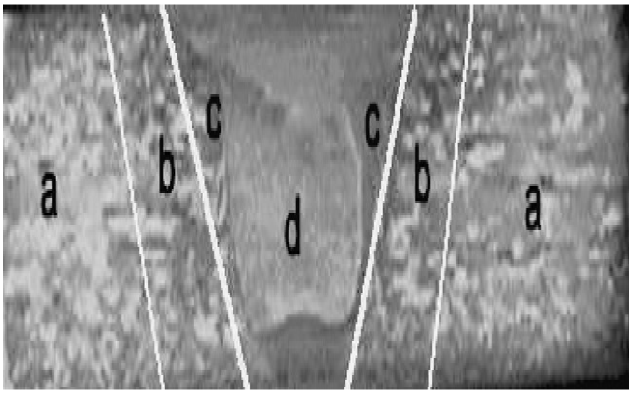

Fig.2. Region of FSW (a) unaffected zone, (b) Heat affected zone (HAZ), (c) Thermo-mechanically affected zone (TMAZ) & friction stir processing zone (FSP) [8-9]

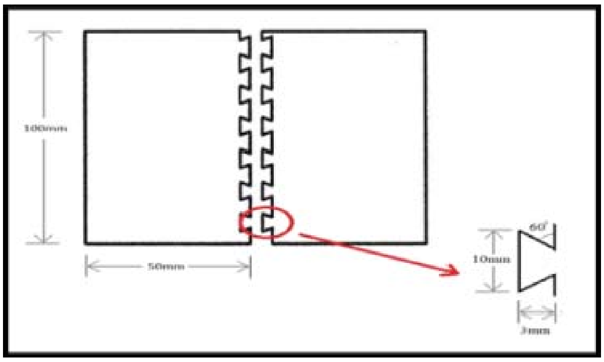

Fig. 3. Dovetail groove

Table 3: Operating parameters

Spindle rotation (RPM)	Transverse speed (mm/min)	Plunge depth (mm)	Title angle degree
1050	200, 325, 500, 600, 725	0.50	0
1320	200, 325, 500, 600 & 725	0.50	0

Fig.4. Friction Stir Welding (FSW) tool

II. EXPERIMENTAL WORKS

A. *Experimental procedures*

A commercially available Aluminium alloy 6061-T6 having 100 mm in length, 75 mm in width and 1 mm in thickness was used. All the plates were machined to dimensions mentioned above with square grooved as shown in the Fig. 3. The square grooves were cut by a wire cut machine to get a minimum gap between grooves. The FSW tool used is shown in the Fig. 4. The operating parameters for the FSW are given in the Table3. The tool was arranged to rotate in the clock wise direction and the work piece was moved in the opposite direction which is called as the advancing side. Only transverse specimen was produced and to be tested on the tensile test. The test specimens were machined from the central part of the joint according to ASTM E8M-01 [10] subsize standard for sheet type material (gauge length 25 mm, width 6 mm, and overall length 100 mm). All samples were produced with minimal defects and conformed to specified dimensions with a tolerance of 0.1mm. The specimens were tested at room temperature using 10 KN Servopulser Series Servo-hydraulic testing machines with front-opening hydraulic grips. Table 4 shows the dimensions of the test specimen as per ASTM [11].

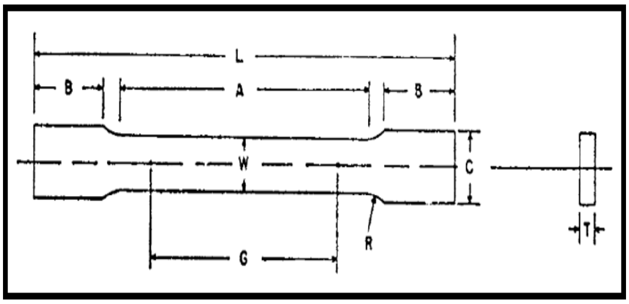

Fig.5. Test specimen as per ASTM [11]

Table 4. Test specimens dimension in mm [11]

Nominal Width	Subsize Specimen
G— Gage length	25± 0.1
W— Width	6± 0.1
T— Thickness	thickness of material
R— Radius of fillet, min	6
L— Overall length	100
A— Length of reduced section, min	32
B— Length of grip section	30
C— Width of grip section, approximate	10

III. RESULTS AND DISCUSSION

A. Surface roughness

Surface roughness refers to the small, closed spaced deviations from the nominal surface and it is measure of peaks and valley caused by machining process by using different tools on different materials. The increase in cutting speed at low feed rate and depth of cut produced smooth surface roughness in machining and as the cutting speed increased low surface roughness produced. In FSW also, low surface roughness was produced at high spindle rotation. In machining, surface roughness add value to performance and also aesthetics sense of the products. The

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surface roughness in FSW process is similar to burnishing action between rotating and moving components. In turning process, low and smooth surface is possible with high rotational speed of the work material and low feed rate of the tool which will contribute to smooth roughness. FSW similarly produced high rotation of the tool and low transverse of the tool contributed low surface roughness. Figure 6 shows the graphical representation between surface roughness and rotation of the tool. The FSW process is similar to burnishing process. It is considered as a cold working process. Compressive action of the tool causes a slight plastic flow of the surface metal to few micrometers which causes metal to be compressed and surface are smoothes out by flattening peak and valleys. At a high spindle speed of 1320 RPM with 200 mm/min transverse speed, a lower surface roughness obtained than other feed rate of 325, 500, 600 and 725 mm/min. At the same time, at low spindle rotational speed of 1050 RPM, for all the transverse speeds, high surface values were obtained when compared to spindle rotation of 1320 RPM and its transverse speeds. Fig. 6 shows the graphical representation of surface roughness and transverse speed.

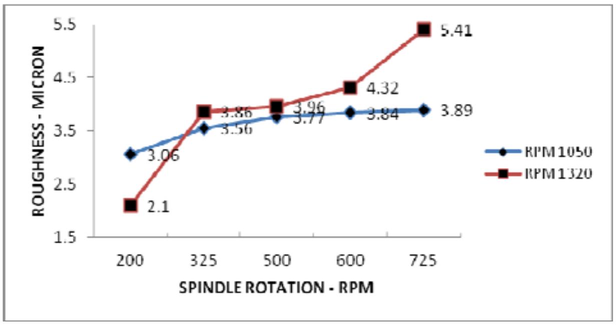

Fig. 6 Roughness vs transverse speed

B. Tensile strength

Tensile strength is one of the methods for determining the mechanical properties of materials, such as strength, ductility, toughness, elastic modulus and strain hardening ability. The materials are tested by ASTM specifications as shown in the Fig. 3 and specimen dimensions are shown in the table 4. At a spindle rotation of 1050 RPM at transverse speed of 200 mm/min, a high tensile value of 240 MPa was obtained and for the other transverse speeds of 325, 500, 600 and 725 the ultimate tensile strength values were 210, 200, 195 and 185 MPa respectively. On the contrary at a spindle rotation of 1350 RPM and for a transverse speed of 200 mm/min, a low value of UTS was 215 MPa was obtained. For the same spindle rotation of 1350 RPM with transverse speeds of 325, 500, 600 and 725 mm/minute the ultimate tensile strength values obtained were 195, 185, 185 and 175 MPa At a low transverse speed of 200 mm/minute high ultimate tensile strength value was obtained and as the transverse speeds were increased the ultimate tensile strength values were low. It is an indication that at low transverse speeds for a given spindle rotation it is possible to reach high ultimate tensile strength values. The reason is that, at low transverse speed, more heat was generated and good bonding occurred between the two joints which were responsible for high value of ultimate tensile strength. At high transverse speeds, the generation of heat was low compared to heat generated at high transverse speeds. Friction created by stirring at low transverse speed generates high heat and good bonding and thus give good strength. When comparing the ultimate tensile strength value of a spindle rotation at 1050 RPM with 200 mm/minute transverse speed it was possible to create UTS strength up to 88 % of the maximum ultimate tensile strength of the base materials at low transverse speeds and low spindle rotation obtained at various parameters. At a spindle rotation of 1350 RPM for the corresponding transverse speed, it was 70 % of the base value of ultimate tensile strength. For the transverse speeds of 325, 500, 600 and 725 mm/minute the ultimate tensile strength obtained were 68%, 65%, 63% and 60% respectively at spindle rotation of 1050 RPM. In evaluating the ultimate tensile strength at spindle rotation of 1350 RPM with transverse speeds of 200, 325, 500, 600 and 725 mm/min, the ultimate tensile strength obtained were 70%, 63%, 60%, 60 % and 57 % respectively. Even at high transverse ultimate tensile strength speed of 725 mm/min values was 57 % of the base metal value of 310 MPa. In FSW welding without dove tail joint, the ultimate tensile strength were only 110 MPa which was 35 % with usual butt joint. It is possible to increase the ultimate tensile strength value by high transverse speeds using dovetail joint.

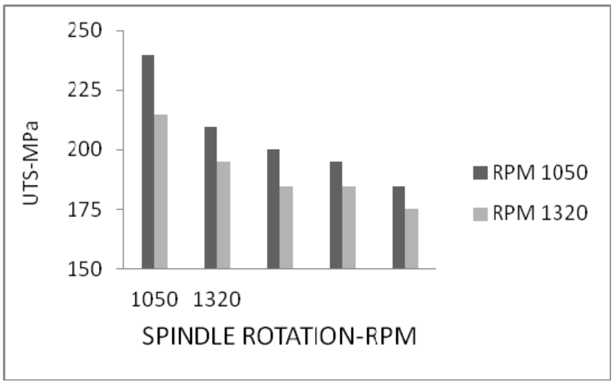

Fig.7. Graphical representation of transverse speed vs ultimate tensile strength (UTS)

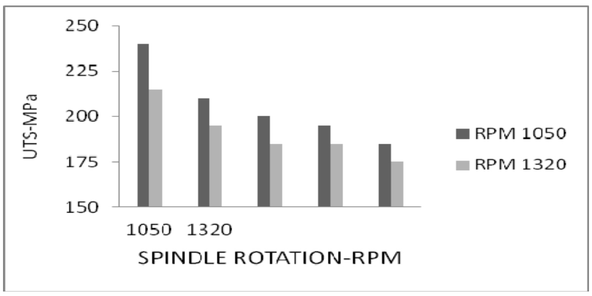

Fig.8. Graphical representation of spindle rotation vs UTS

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B. Fracture strength

Fracture is the separation of an object or material into two, or more, pieces under the action of stress [10]. Fracture of a solid always occurs due to the development of certain displacement discontinuity surfaces within the solid. If a displacement develops in this case perpendicular to the surface of displacement, it is called a normal tensile crack or simply a crack; if a displacement develops tangentially to the surface of displacement, it is called a shear crack, slip band, or dislocation. The fracture strength of the base metal is 96.5 MPa and in this research work, it was possible to have fracture strength as high as 56 MPa at 1050 rotational speed and at 200 mm/minute transverse speed and as low as 49 MPa at 725 transverse speed.

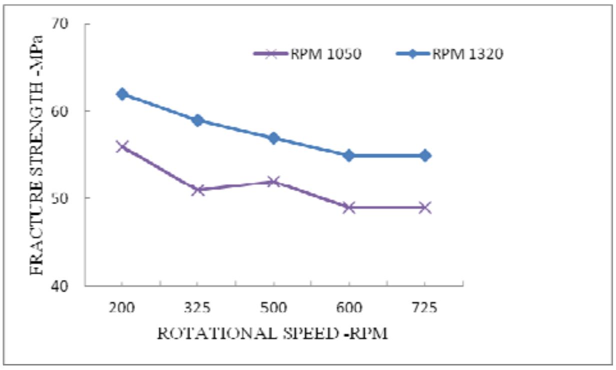
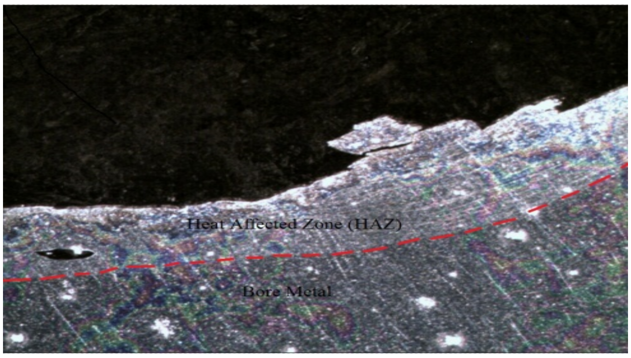


Fig.9. Rotational speed vs fracture strength

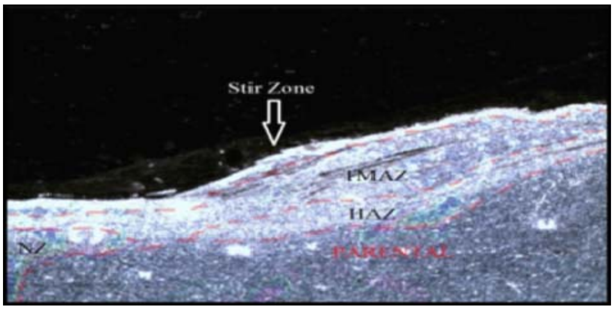
On the other hand, at 1320 RPM, fracture strength was 62 MPa as high value at 200 mm/min transverse speed and low as 55 MPa at 6725 transverse speed. Figure 9 shows the graphical representation of rotational speed and fracture strength. The fracture strength of 96.5 MPa could not be achieved due to the dovetail groove as well as the heat at nugget. The fracture failure has occurred close to nugget in most of the samples.

C. Microstructure

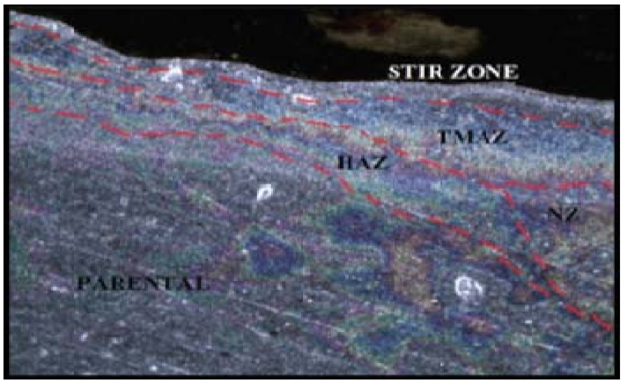
Fig.10 (a) to (c) shows SEM view on the micrograph by FSW. Fig.10 (a) represents a macro section of the thermally heat affected zone (TMAZ). In this region, there are cracks / tear of the material due more ununiform plunge depth and also due to the metal not flat while doing FSW. Fig. 10 (b) and (c) show the macro section at a spindle rotation of 1350 RPM with transverse speed of 325 and 600 mm/minute. TMAZ and HAZ is shown as white band in Fig.10 (b).



(a) Macro section of Aluminium



(b) Macro section of Aluminium with 1320 RPM



(c). Macro section of Aluminium with 1320 RPM and 600 mm/min

(d). Defect formed due to larger welding of 4 mm diameter tool is used

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Fig.10. (a) to (c) SEM view for micro structre and & (d), (e) defects in FSW

Fig.10 (d) and (e) show the a defect formed due to larger diameter of pin used to have more contact area thereby increasing the heat generation which was responsible for the defect. Larger diameter of the tool is not suitable for a 1mm thickness. Larger area of the tool increased the frictional zone and more heat was generated which caused the material to have unsteady plastic deformation. Selection of the tool pin diameter played vital role in Friction Stir Processing (FSP) zone.

IV. CONCLUSION

The main conclusions are summarized below:

1. Friction stir welding gives good result in joining dovetail groove joint.
2. The mechanical properties obtained by dovetail joints reached to 50% of the base metal strength at high transverse speeds and 65% to 70% of the base metal strength at given spindle rotation.
3. If suitable welding parameters are set then maximum ultimate tensile strength is possible to obtain.
4. Fracture occurred either in the heat affected zone or in the weld joint, however, fracture occurred at the base material of all the parameters.
5. Surface of base plate should be flat. Root joint of soft weld metal is flat straight in this way.
6. By FSW welding, it is possible to get smooth surface on the welded zone due to burnishing action between rotating surface and base metal.
7. It is necessary to identify tool pin diameter based on thickness of the material, if not weld defects are likely to occur which will damage the performance of the welded parts.

V. FURTHER RESEARCH WORK

It was planned to extend the research further by using various tool pin diameters, title angle of the tool, dissimilar materials with varying thicknesses. Square groove joint can also used to test out the FSW. Apart from testing the UTS, fracture strength, fatigue life of the weldment can also be tested.

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