Study on Tensile Properties of Friction Stir Welded Joints of 6061-T6 Aluminium Alloys

[1]Yogesha C, [2]Suresha C N, [3]Rajaprakash B M, [4]Sarala Upadhya

[1]Department of Mechanical Engineering, Jyothy Institute of Technology, Bangalore-INDIA
[2]Department of Mechanical Engineering, Amruta Institute of Engineering & Management Science, Bangalore-INDIA
[3]Department of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore University, Bangalore-INDIA
[4]Department of Mechanical Engineering (Former), University Visvesvaraya College of Engineering, Bangalore University, Bangalore-INDIA.

Abstract* - Friction stir Welding (FSW) is a solid state joining process used to weld similar and dissimilar materials which are difficult to weld by conventional welding process. Weld quality is mainly affected by welding input parameters such as tool probe geometry, tool rotational speed, welding speed and also the forces during welding. This paper presents a systematic approach to study the effect of parameters of Friction Stir Welding of thin aluminum alloy sheet. An attempt has been made to join the aluminum alloy of 6061-T6 of 2.0 mm thick by FSW using conventional milling machine. It was found that joints with rotational speed of 1000 rpm showed maximum tensile strength (UTS). Also joint strength shows an increase with respect to welding speed.

Keywords: ***FSW, tool geometry, welding speed, axial force, tensile strength***

I. INTRODUCTION

In Engineering Field weight and strength plays a predominant role in structures, this concern is addressed by aluminum alloys of high strength and light in weight. These are used in various applications like defense, automobiles and ship building etc., The 6xxx aluminum alloys are known as the silicon and magnesium type. These two are the main alloying constituents in all 6xxx grade aluminum alloys. They are moderate strength alloys which are heat treated by cold working. The heat treatable alloys have excellent spot and fusing weldability, can also be furnace brazed easily. The 6xxx aluminum alloys are applicable in high-strength structural members, rolling stock, marine applications, vehicles, architectural applications, etc. These alloys are difficult to joint by conventional welding process. For this type of aluminum alloys, Friction Stir Welding (FSW) process is proven for joining.

Friction stir welding process one of the solid state joining process and its produces sound joint compared to other welding process. Friction stir welding process consists of different process parameters like rotational speed, welding speed, Tool pin diameter and these parameters are plays important role in achieving quality weld. P Staron et.al.[1] studied FSW joints of 3.2 mm thick AA2024 Al-sheets that have been welded under mechanical tensioning were analyzed, they found that large compressive stress has been induced in the weld by applying mechanical tensioning during welding. R.K. Kesharwani et.al.[2] joined 2.0-mm thick AA5754-H22 and AA5052-H32 sheet metals with optimized tool design and process parameters to maximize the weld strength and total elongation reducing the surface roughness and energy consumption, they found that the formability was improved by 27% using the modified conical tractrix die. A. Scialpi et.al.[3] studied the effect of different shoulder geometries on the mechanical and micro-structural properties of a FS Welded joints. FSW process was used to join 6082 T6 aluminium alloy of 1.5 mm thick. They observed that the best joint has been produced by a shoulder with fillet and cavity. Shuja Ahmed et.al.[4] joined AA6XXX series aluminium alloys of thickness 0.44 mm, in both butt and lap fashion. They established the measure of joint’s tensile strength (by conducting both transverse and longitudinal tension tests) and the micro-hardness. They found that the lap welds are having better tensile properties than the butt welds in both transverse and longitudinal tension tests. M.Muthukrishnan et.al.[5] Butt welded of cast aluminum alloys of 3 mm thick, Al-6082-T6 by varying different combinations of tool rotation speed, welding speed, and axial force, each at different levels. They analyzed the effect of welding parameters on the weld performance of the joint by conducting tensile and hardness tests.

J. C. Hou et.al.[6] investigated the effect of rotation speed on microstructure and mechanical properties of 6061-T6 aluminum alloy of 4 mm thick FS welded by specially designed tool with unequal shoulder diameters at a constant welding speed of 150 mm/min. They found that tensile strength, density at the weld zone and grain size of weld joints depends on tool rotational speed. M. Habibnia [7] Studied the Microstructure and mechanical properties of weld nugget in FS Welded dissimilar sheets of 5050 Al alloy and 304 stainless steel with 3-mm thick. They observed that improvement in tensile strength of welded joints by FSW was achieved by varying the process parameters, like tool rotational speed, increasing tool feed rate, plunge depth and tool offset. Heidarzadeh et.al.[8] studied the FSW joints of pure copper plates of 2 mm thick. The different traverse speeds and rotational speeds were considered as welding parameters. They found that the peak temperature was the dominant factor in controlling the grain size and mechanical properties, where the fine grains can be achieved at low rotational speed as well as high traverse speed. Ana C. F. Silva et.al.[9] studied FSW joint geometries of AA6082-T6 aluminium alloy of 3-mm and 2mm thick for butt, lap and T joints. They found that Ultimate Tensile strength of each joint configuration can be achieved by optimization of FSW process parameters. Pierpaolo Carlone et.al.[10] studied FSW joints of AA2024-T3–Cu10100 dissimilar material of 2mm thick by off-setting the tool probe towards the aluminum sheet for selected process parameters. They observed that, Microstructure variation significantly affects the mechanical properties and micro-hardness distribution in the cross-section of the joint. Yuqing Mao et.al.[11] Studied the microstructure, secondary phase particles transformation, and mechanical properties of FSW joints of 2 mm thick 2060 Al-Li alloy plates at a welding speed of 95–150 mm/min and rotation speed of 750–1500 rpm. They found that defect-free joints were produced by varying FSW parameters and weld nugget size increased initially and decreased with increased rotation speed and decreased welding speed. P. Venkateswaran et.al. [12] studied the FSW joints of 3.25 mm thick heat treated Al–Mg–Si and strain hardened Mg–Al–Zn alloy sheets. They evaluated tensile strengths and observed that failures occurred along the weld interface, which is due to formation of intermetallic compounds in the weld joints, brittle failure of the dissimilar weld joints and low tensile strengths.

In the present work an attempt has been made to identify the simple criterion to produce defect free welds for different FSW parameters. Also to analyze the effect of FSW tool rotational speed, shoulder diameter, plunge depth, welding speed and axial force on the formation of weld.

II. EXPERIMENTAL METHODOLOGY

A. *Preparation of work material*

The work piece material selected in the present work is aluminum alloy AA6061-T6 plate of size 300x75x2.5 thick. Table I shows the chemical composition of AA6061-T6 aluminum alloy material.

Table I: Chemical Composition of AA6061-T6 alloy material (in weight percent)

Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
95.8 - 98.6	0.04 - 0.35	0.15 -0.4	Max 0.7	0.8-0.12	Max 0.15	0.4 - 0.8	Max 0.15	Max 0.25

B. *Preparation of FSW Tool*

Tool made of HCHCR (D2) material with flat shoulder with cylindrical pin was used. The tool shoulder diameter of 18 mm, pin of cylindrical shape was used, Fig.1 shows tool used. The chemical composition of tool material is shown in Table II.

Fig. 1: HCHCR FSW tool

Table II: Chemical Composition of HCHCR tool material (in weight percent)

C	Cr	Si	P	Mo	Mn	V	S
1.5	11-13	0.3	0.03	0.9	0.45	1	0.03

C. *Preparation of Welded joint*

Two work-piece material plates were rigidly clamped on the bed of conventional Milling machine using specially designed mechanical fixture with axial force sensor mounted on it. Welded joints were prepared using Universal Milling Machine (Make: BFW, Model: UF1, shown in Fig. 2) after conducting trial studies to attain range of FSW process parameters. The range of FSW parameter selected were table traverse speed are 63 to 100 mm/min, tool rotational speed are 500 to 1000 rpm and tool plunge depth 1.85 to 1.90mm. The details of process parameters selected within the range as shown in Table III.

Table III: Details of welding parameters

Weld No.	Rotational Speed (rpm)	Traverse Speed (mm/min)	Plunge Depth (mm)
FSW-1	**1000**	**100**	**1.85**
FSW-2	**1000**	**100**	**1.90**
FSW-3	**1000**	**80**	**1.85**
FSW-4	**1000**	**80**	**1.90**
FSW-5	**1000**	**63**	**1.85**
FSW-6	**1000**	**63**	**1.90**

Friction Stir Welding was carried out on a conventional Universal Milling Machine (Fixed with vertical head) with specially designed Mechanical fixture fixed with the axial force sensor unit. In the present work, important process parameters considered are tool rotational speed, tool traverse speed (feed) and plunge depth to produce ―defect-free‖ FSW joints.

Fig. 2: FSW set up on Universal Milling Machine with vertical head

D. Preparation of Tensile Testing Specimen

The welded plates were subjected visual inspection and X-ray radiography to ascertain the soundness of weld. Fig. 3(a), 3(c), 3(e), 3(g), 3(i) and 3(k) shows the weld joints and Fig. 3(b), 3(d), 3(f), 3(h), 3(j) and 3(l) shows X-ray radiography image on the weld.

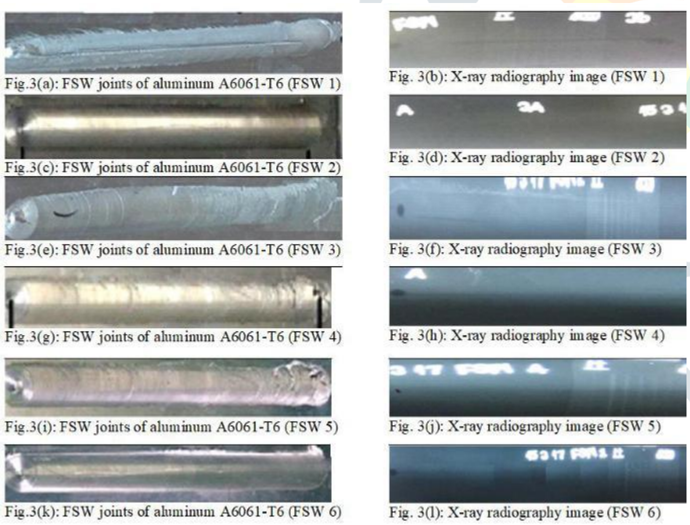


Fig.3(a): FSW joints of aluminum A6061-T6 (FSW 1)
Fig. 3(b): X-ray radiography image (FSW 1)
Fig.3(c): FSW joints of aluminum A6061-T6 (FSW 2)
Fig. 3(d): X-ray radiography image (FSW 2)
Fig.3(e): FSW joints of aluminum A6061-T6 (FSW 3)
Fig. 3(f): X-ray radiography image (FSW 3)
Fig.3(g): FSW joints of aluminum A6061-T6 (FSW 4)
Fig. 3(h): X-ray radiography image (FSW 4)
Fig.3(i): FSW joints of aluminum A6061-T6 (FSW 5)
Fig. 3(j): X-ray radiography image (FSW 5)
Fig.3(k): FSW joints of aluminum A6061-T6 (FSW 6)
Fig. 3(l): X-ray radiography image (FSW 6)

The tensile specimens were prepared by using Wire – Electrode cutting machine as per ASTM-E8/E 8M-08 standard shown in Fig. 4. The specimens were prepared perpendicular to the welding direction.

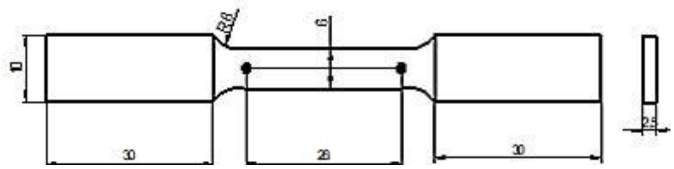


Fig. 4: Schematic diagram of tensile test specimen as per the ASTM-E8/E 8M-08 standard

The tensile tests were carried out at a room temperature on Universal Testing Machine shown in Fig. 5. Tests were carried out at a strain rate of 1 mm/min, and specimens were recorded for each parameter condition. From these the Ultimate Load, Ultimate Tensile Strength, Maximum Displacement and Young's modulus characteristics are noted.

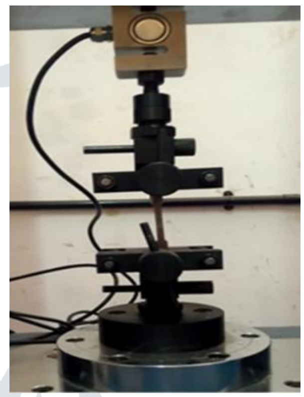
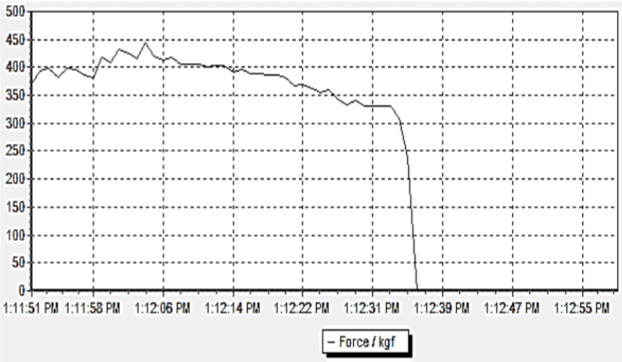


Fig. 5: Universal Testing Machine (MCS)

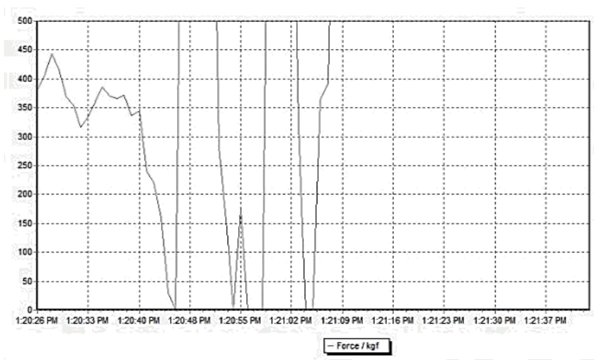
III. RESULTS AND DISCUSSIONS

A. Axial force measurement

During FSW process the forces were measured and recorded by Dynamometer separately. Using dynamometer it is possible to capture the axial force during FSW process. The force v/s time plots for the joining of AA6061-T6 alloys are presented in Fig. 6. As the tool rotates and moves downward by plunging the work-piece of given depth and the tool moves in welding direction as it rotates, softens and joins the two plates. The Fig. 6(a) indicates the less variation of force during the welding at spindle speed of 1000 rpm and welding speed of 100 mm/min compared to the welding at spindle speed of 1000 rpm and welding speed of 80 mm/min as shown in Fig. 6(b).



6 (a)



6(b)

Fig. 6: Variation of Force in z-direction during FSW process

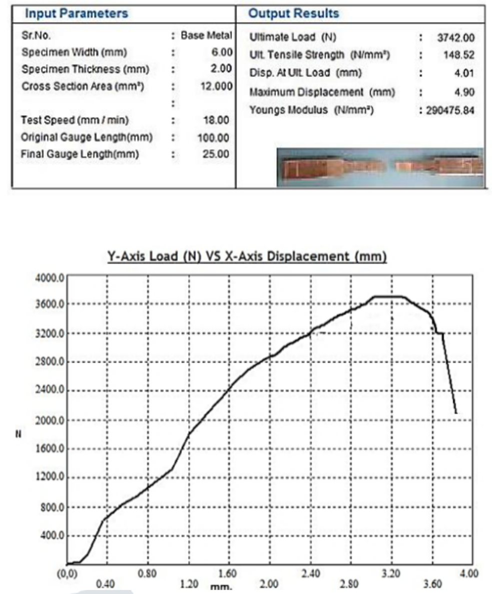


Fig. 7: Tensile test result of Base Metal with specimen

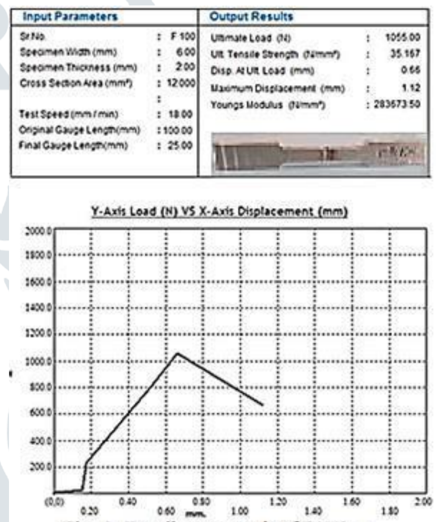


Fig. 8: Tensile test result of FSW – 1

B. Tensile tests of FS welded specimens

The tensile properties of the AA6061-T6 alloy are listed in Table IV. for welds prepared. Each property value in this table represents of individual specimen. Fig. 7, 8, 9, 10, 11, 12 and 13 shows graph of individual test specimen.

The results shows that a weld joint efficiency (weld/base material tensile strength) of 91 % for butt joint. Further the strength of welded joint can be improved by optimizing the process parameters.

Table IV: Tensile test results of base material and FSW joints

Weld No.	Base Material	FSW-1	FSW-2	FSW-3	FSW-4	FSW-5	FSW-6
Ultimate Load (N)	3742	1055	1262	2467	3409	2515	2467
Ultimate Tensile Strength (N/mm^2)	148.52	35.16	42.06	82.33	113.63	83.83	80.733
Displacement at Ultimate Load (mm)	4.01	0.66	0.86	4.59	3.39	3.80	2.72
Maximum Displacement (mm)	4.90	1.12	1.00	5.35	3.84	4.57	3.50
Young's Modulus (KN/mm^2)	290.47	283.67	233.59	100.57	205.98	124.44	192.62

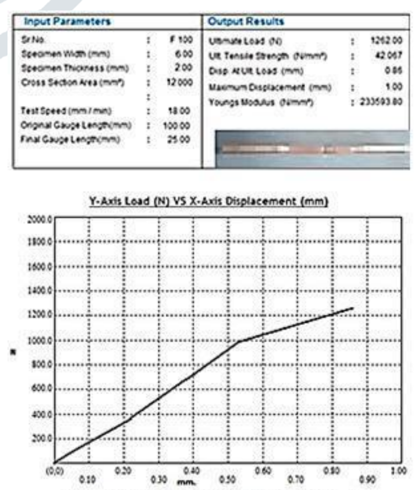


Fig. 9: Tensile test result of FSW – 2

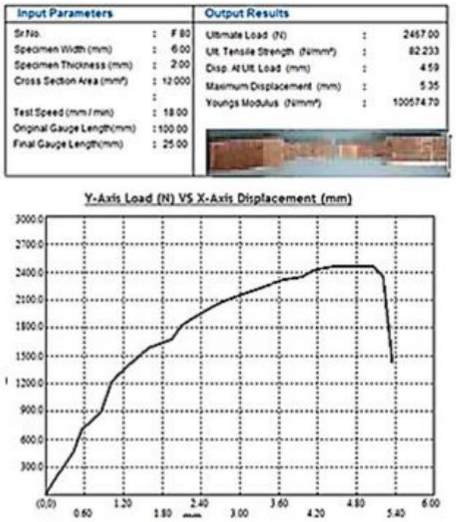


Fig. 10: Tensile test result of FSW – 3

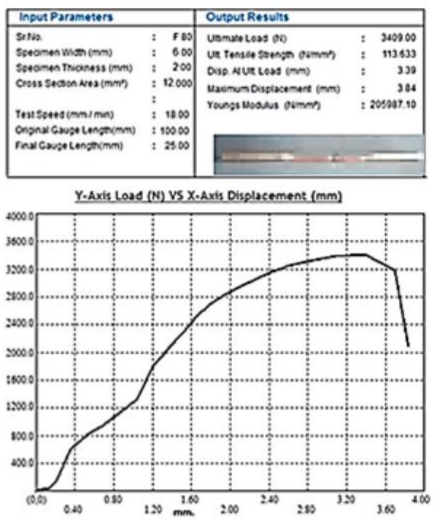


Fig. 11: Tensile test result of FSW – 4

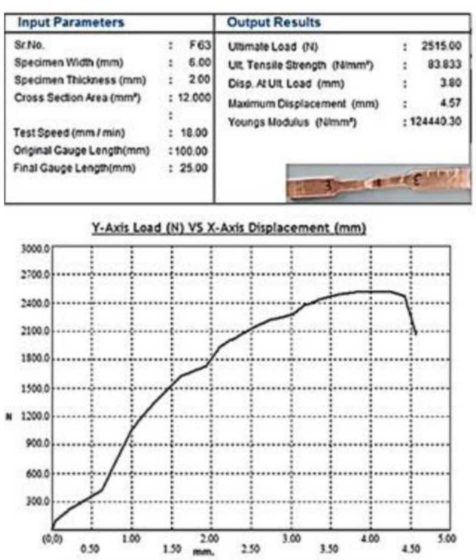


Fig. 12: Tensile test result of FSW – 5

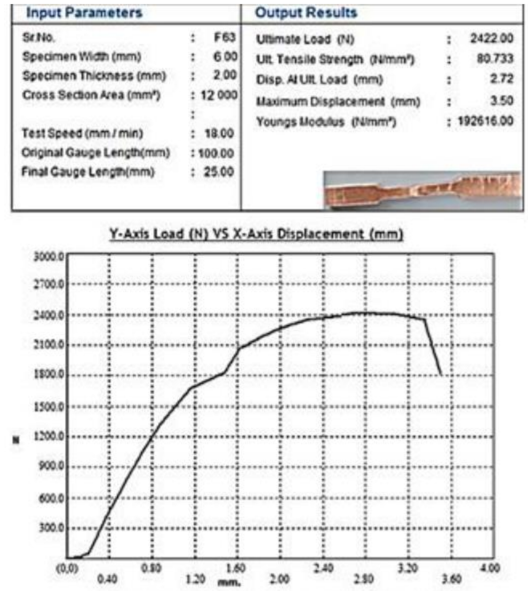
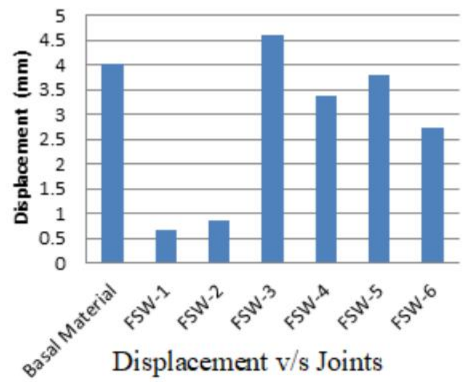


Fig. 13: Tensile test result of FSW – 6



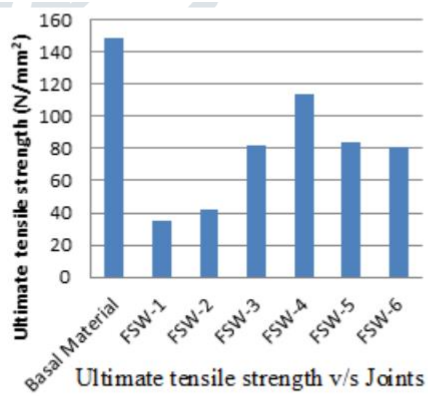


Fig. 14 (a)

Fig. 14 (b)

Fig. 14: Strength of different FSW joint

IV. CONCLUSION

The tensile properties such as Ultimate tensile strength, Young's Modulus, percentage of elongation of joints were recorded. The ultimate tensile stress of un-welded base metal is 148.52 N/mm2. However, tensile strength of FSW joints is vary from 35.16 N/mm2 to 113.63 N/mm2, and Young's Modulus of un welded base metal is 290.47 KN/mm2, whereas FSW joints is vary from 100.57 KN/mm2 to 283.67 KN/mm2. These results show that varying the table traverse speed and keeping other parameter constant, resulting in maximum tensile strength. For table traverse speed of 80 mm/min exhibited higher strength values with joint efficiency of 91.1% which is nearer to strength of base material.

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