The Effect of Process Parameters on Microstructural and Mechanical Properties of Friction Stir Welded Age-Hardenable Aluminium Alloy

Vuppula Prasanna, P. Ramesh Babu

Abstract*: FSW has become the most effective technology in solving problems that have reached the profiled sheets with the continuation of material, particularly in the aerospace industry, with the use of different joining techniques that require high ductility and tensile strength. Current study, FS weldments AA6061-T6 were successfully obtained with varying processing parameters and were mechanically and metallurgically characterized. This paper illustrates macrostructure analysis, influence of tool geometry and process parameters, Fractography analysis microstructure analysis, microhardness of aluminium alloy AA6061-T6.

***Keywords:* AA6061-T6, Friction stir welding, Grain size, Mechanical properties, Microstructural studies, stir zone, Tool rotational speed, Travel speed.**

I. INTRODUCTION

Fig 1 Top and bottom of the joint

A. Visual inspection results

Visual inspection is displayed on welding samples obtained from a variety of welding Parameters to verify defects like surface irregularities, high flash, and lack of penetration or surface open tunnels.

B. Visual Inspection before welding

After preparation two plates are clamped in welding fixture which qualities welding.

- Edges of plates before welding should have good finish, with cleaned surface from oil and dirt to get defect free welded joints.
- Securely fix plates without any gap between the welding edges, this gap if it exists effects weld quality and then the welded joint may be has a defect in the welded line.
- Positioning accurately two edges of plates on the same axis of welding tool (z axis), otherwise bending occurred due to force applied from tool shoulder and probe on the plate that produce gab dawn the interface of two plates.

C. Radiography Inspection Results

According to radiography inspection results (conducted using 100 KVA and 5 mA source, Exp. time 36 sec), only two (plates) joints had been accepted from the inspector as shown in Fig 2 (sample 1, 2 and 3, 4) FSW 5 and 6 have internal defect in weld line. The type of defect is evaluated as incomplete fusion (tunnel or worm hole), incomplete cap. Radiography inspection results did not (as expected) reveal any type of porosity or blow holes or any type of hot cracking because no melting and freezing occurs in welding process due to the solid state nature of (FSW) process [1].

Fig 2 Radiographic inspection film

(a) 1 &2 Samples 800rpm with 60mm/min
(b) 3 &4 Samples 1200rpm with 150mm/min

II. METHODOLOGY

AA6061-T6 belongs to a group of heat treatable 6xxx series which contains Al-Mg-Si as major composition. The required welding sizes of 120mm x 100 mm x 3mm were used. The cast AA6061-T6, Al-Si-Cu or Al-Si-Cu-Mg belongs to aluminium alloys. Copper and magnesium grows at its peak and elevated temperatures when its strength and hardness grows. It has good weldability and corrosion resistance. The sides of the plates will be checked for parallel to the correct clamp in the FSW divisions, which will consolidate the movement for the welding process of movement. The composition and properties of AA6061-T6 are listed in Table 1and Table 2.

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Table 1Mechanical properties of Aluminium of Base metal AA6061-T6

6061-T6	Cu	Mg	Mn	Fe	Cr	Si	Al
Standard	0.31	0.99	0.08	0.25	0.16	0.66	Balance
Observed	0.30	1.00	0.06	0.19	0.13	0.67	Balance

Table 2 Chemical Composition of Aluminium Base metal AA6061-T6

Alloy AA6061-T6	0.2% Yield Strength (MPa)	UTS (MPa)	Elongation (%)	Hardness (VHN)
Standard	198	240	26	105
Observed	183	236	22	103

III. RESULT AND DISCUSSION

The tool rotation speed is expected to have a momentous impingement on the tensile tests of the joints. Base metal yield strength and tensile strength are 198 MPa, 240 MPa. 1200 rpm with 150mm / min, 5KN axial force, 178 MPa tensile strength, 7% of elongation and 78% joint efficiency. Rotational speed of 800 rpm, the joint is designed to show more tensile strength. To interpret cause of tensile features on joints, macrostructure, microstructure analysis and microhardness are performed and the results are displayed in the following sections [6, 7].

Table 4 Process Parameters on Al alloy AA6061-T6

S. No	Rotational Speed (rpm)	Travel speed (mm/min)	Width (mm)	Thickness (mm)	Sp. Gauge length (mm)	0.2 Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)	Joint Efficiency (η)
1	800	150	5	3	25	156	215	8.0	89.5
2	1200	150	5	3	25	150	210	7.0	87.5
3	800	60	5	3	25	136	178	7.0	74.1
4	1200	60	5	3	25	124	173	6.0	72.0

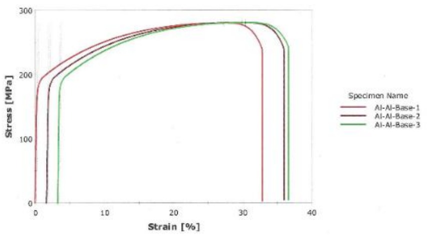


Fig 4 Graph for stress Vs strain aluminium sample base metal

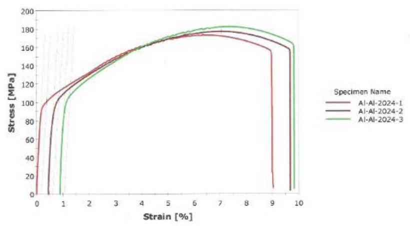


Fig 5 Graph between Stress Vs Strain for rotational speed 800 rpm and travel speed of 60mm/min

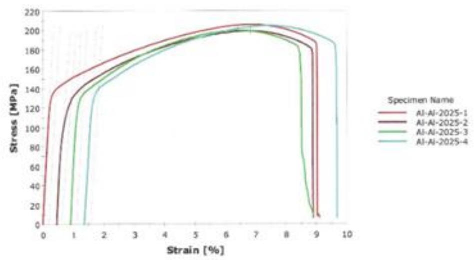


Fig 6 Graph between Stress Vs Strain for rotational speed 1200 rpm and travel speed of 150mm/min

Fig 7 Fracture location of the tensile specimens for the BM and joints welded at constant rotation speed of 800 rpm and 1200rpm.

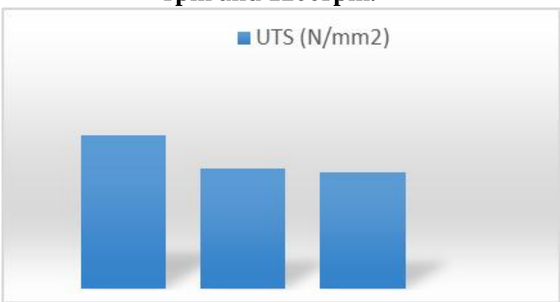


Fig 8 Graph between Stress Vs Rotational speed for Base Metal, Sample 1 and Sample 2

Fig 7 tensile strength of aluminium alloy AA6061-T6 reveals the influence of rotation speed in the joint. At low rotation speed (800 rpm), the tensile strength is high. At 800 rpm, it increases the tensile strength and reaches maximum. If the rotation speed is increased 1200 rpm, the tensile strength of the joint is reduced [4]. Higher tool rotation speed (1200 rpm) causes higher grain size as a result of high heat input per unit length and slow cooling rate in FSW zone, leading to lower tensile characteristics of the joints. High rotation speed releases stirred materials to the upper surface, resulting in the micro-voids in the SZ causing the lower tensile characteristics of the joints. If the low rotation speed results low thermal input for 800 rpm per unit length, the result does not have sufficient plastics and is one of the causes of high tensile characteristics of the joints. At a rotating speed of 1200 rpm, displays minimal tensile strength and can cause optimum thermal production.

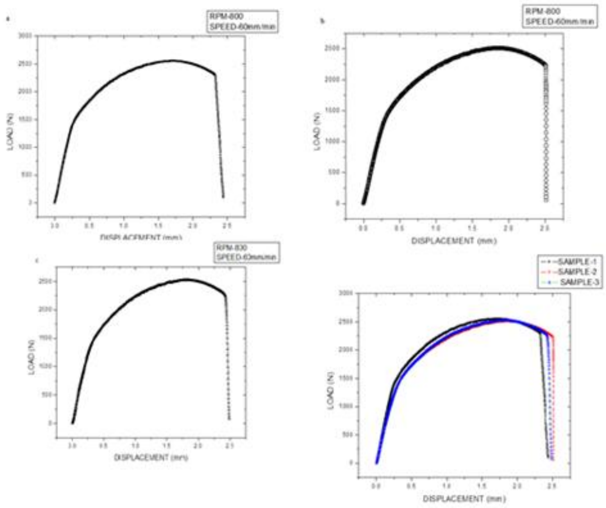


Fig 9 Load Vs Displacement a) Sample 1 b) Sample 2 c) Sample 3 with rotational speed 800rpm and Travel speed of 60mm/min.

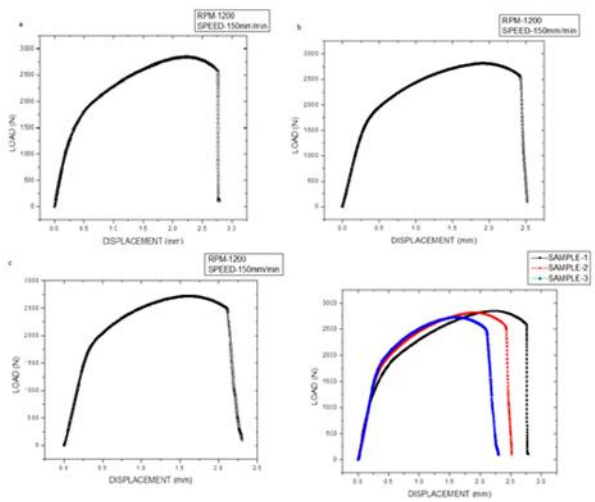


Fig 10 Load Vs Displacement a) Sample 1 b) Sample 2 c) Sample 3 with rotational speed 1200rpm and Travel speed of 150mm/min.

Microhardness

Micro hardness is measured in the mid area across the width of the plate shown in Fig 11. Parent metal has hardness of 105Hv, less than the nugget zone, more than TMAZ and parent metal. Two main reasons for better hardness: (i) Nugget zone grain size is better than parent metal, grain refining has a vital role in maximum strength. (ii) Intermetallic compounds are also reason for hardness improvement. The difference in hardness between the heat affected zone and the stir zone is attributed to grain refining in the stir zone. The highest hardness in the joint generated with the rotational speed of the 800 rpm in the TMAZ. At 1200 rpm the maximum value of 117Hv in the stir zone commonly associated with the rotation of the joint, can cause the best tensile properties of the joint.

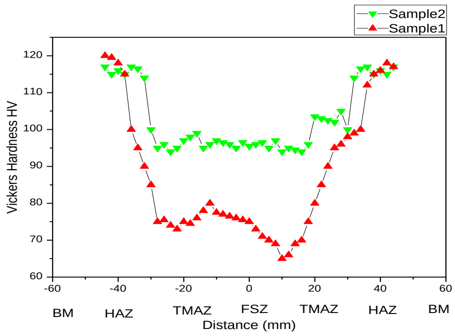


Fig 11 Vickers hardness graph for sample 1 and sample 2

Microstructure

The microstructure along the cross section of the base metal AA6061-T6 reveals coarse second phase particles and large recrystallized grains. Grains are elongated along the rolling direction. Fig 12 (a, b) shows the optical micrograph taken at the surface of the base plate. The optical microstructures taken along the cross section in the transverse direction of FS welded joints of al alloy AA6061-T6 are observed with three different distinctive zones viz. WN, TMAZ, and HAZ, and these three zones are observed in the FS weld.

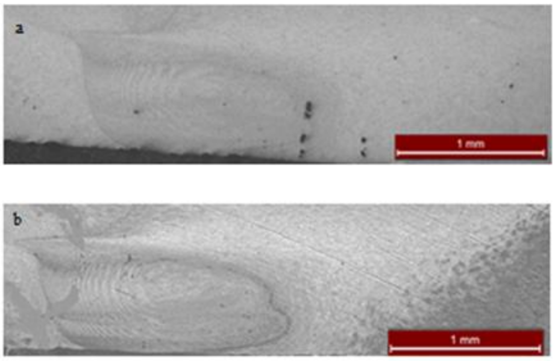


Fig 12 (i) (a), (b) Macrostructure of cross section Aluminium AA6061-T6 alloy

The optical micrographs taken in the areas of stir zone for the joints are displayed in the fig12 (a, b). Above microstructures shows, significant difference in average diameter of grains in stir zone and coarse grains in the base metal are converted to fine grains in the stir zone. Hence, average grain diameter (AGD) on weldments was done by using ASTM Grain size measurement. At 1200rpm 5-8µm grains are observed due to high tensile characteristics in the joint. Optical micrographs were carried across different areas throughout the weld, but for comparison purposes, the SZ-TMAZ interface areas micrographs were shown in fig12 (a, b). There is an appreciable difference in the TMAZ grain size. Grains in nugget area are better than TMAZ. Which have minimum grain diameter shown in fig12 (b). However, at 800rpm grains are larger and at 1200rpm grains are small. Microstructures shows that the metal is pulled from advancing side during stirring action of the tool, therefore it leads to elongation of grains in TMAZ.

X-ray Diffraction

XRD is most direct and accurate analytical method of determining the total amounts of existence and elements in a specimen. According to the elemental data from the XRD analysis, the alloy is slightly more than Si and Mg. The high amount of AA6061-T6 allocated from XRD analysis is high corrosion resistance and good efficiency. The XRD only refers to alloy around micro constituents. X-ray diffraction is a non-destroying analytical technique versatile, and with the help of obtain information for recognition and size of different crystalline compounds known as "phase" compounds in the material. X-ray diffraction of the structure is based on the crystallographic planes, the alloy Mg2Si and Al2O3 were analyze and described. Determination of structural units are the dependence of diffracted radiation and 2θ deflection angle. Composition phase has been diagnosed by qualitative analysis by X-ray diffraction, X-ray diffraction conducted by the Panalistic X'Pert PRO MPD.

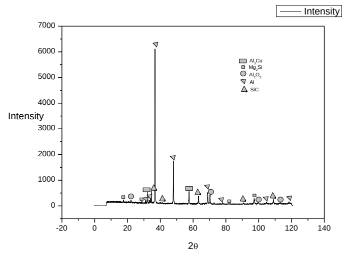
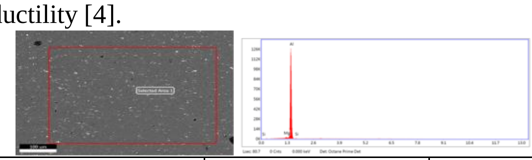


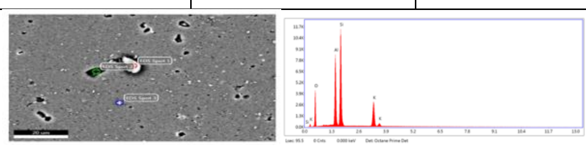
Fig 13 XRD pattern obtained from the Aluminium alloy 6061-T6

SEM with EDAX

The results of EDS analysis of the base metal AA6061-T6 aluminium alloy is presented in Fig 19 (a, b, c). Images of the base metal shown in Fig 19 (a) and (b) which explore the presence of particles in varying size. The EDS analysis was carried out at the base metal surface (at Area 1 in Fig 19 (a)) particles and their results are plotted in Fig 19 (a), (b) and (c) respectively. The results indicate that the particles are enriched with the metal Al and therefore, they are Al2O3 (second phase particles) and Mg2Si (intermetallic particle) as reported by other authors [2].The most commonly found particles in AA6061-T6 are Mg2Si, Al2O3 and SiC [3]. These particles are also responsible for its tensile strength and ductility [4].



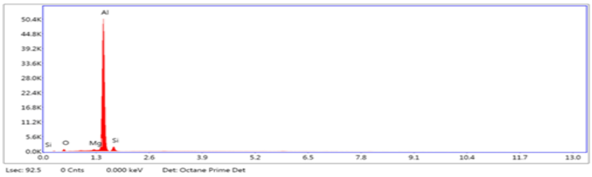
Element	Weight %	Atomic %
Mg K	1.31	1.45
Al K	97.75	97.64
Si K	0.94	0.91



EDS Spot 1

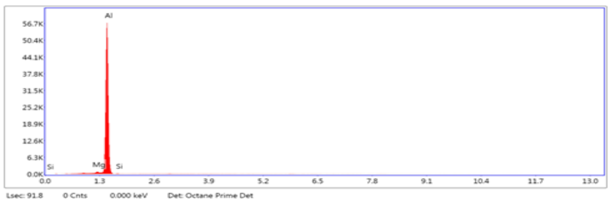
Element	Weight %	Atomic %
Al K	18.67	15.57
O K	36.75	51.68
Si K	31.50	25.23
K K	13.08	7.52

EDS Spot 2



Element	Weight %	Atomic %
O K	5.05	8.24
Mg K	1.22	1.31
Al K	85.22	82.52
Si K	8.51	7.92

EDS Spot 3



Element	Weight %	Atomic %
Mg K	1.28	1.42
Al K	97.83	97.72
Si K	0.89	0.86

Fig 19 Results of EDS analysis of the base metal 6061-T6

(a) SEM image showing the presence of particles

(b) Results of EDS analysis

IV.CONCLUSION

Weldments generated at 60 mm / min, 150 mm / min welding speed and 800 and 1200 rpm at different rotating speeds are sound. Void defects occur at a rotational speed of 800rpm at the interface of parent metal and TMAZ. During FSW, Increasing the temperature and thermal heat input of the weldments cause less grain structure and large secondary phase particles at nugget zone. At low rotational speeds, the defective joints have high hardness and UTS with low elongation. A partial cleavage type with dimples and cleavage facets are formed in the joints. In addition, joints having high rotation speed explains high elastic fracture other than joints having low rotation speed.

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