Influences of Welding Speed on Mechanical Properties of Friction Stir Welded Joints of AA2014-T6 Aluminium Alloy

C. Rajendran, S.Anudeep, R.Ajith

Abstract: ***The current work is concentrated on the influence of traverse speed on mechanical properties of Al alloy (AA2014), by trailing one of the process parameters and while others were kept constant. The joint fabricated from a rotational speed of 1500 rpm, welding speed of 40 mm/min, shoulder diameter of 6 mm and tilt angle of 1.5º yielded superior tensile strength compared to their counter joints. Due to the formation of defect-free, balanced material flow, uniform distribution of precipitates in the processed region.***

Keywords: ***Al-Cu alloy, FSW, Traverse speed, Microstructure, Tensile strength.***

I. INTRODUCTION

Al 2xxx is having a high strength to weight ratio, good formability and high corrosion resistance, have been widely applied as critical structural material in many industries, such as aerospace, shipbuilding, and automobile. Nevertheless, this type of Al alloy is very difficult to weld by the conventional welding process. Which in turn causes hot cracking, the woe of welding Al alloys must be provoked. Hence, careful consideration to be needed to join high strength aluminium alloys by using traditional welding process. It showed that Al alloy difficult to weld by fusion welding [1]. FSW as a solid-state process has proved effectively and efficiently to weld metals, such as aluminium and magnesium alloys, which are widely applied for critical structural fabrication industries [2-11]. It eliminates completely fusion welding problems and mechanical pins like screw, bolt& nut and rivets. Therefore, to achieve a better quality of friction stir welded joints by adjusting the FSW parameters. Zhang et al [12] studied the effect of welding parameters on microstructure and mechanical properties of FSW joints of super high strength Al-Zn-Mg-Cu aluminum alloy, concluded that the grain size of the SZ decreases with increasing welding speed or decreasing rotational speed during FSW, subsequently found that the strengthening precipitates in the HAZ were deteriorated and some of the coarsened due to thermal cycle. From the literature [1-12], it is understood that more work has been done to investigate the effect of friction stir welding parameter on microstructural characteristics and tensile properties of the different grade of aluminum alloys. None analyzed the effect of welding speed on microstructural characteristics and tensile properties of friction stir welded joints of the AA2014-T6 aluminum alloy.

II. METHODOLOGY

The parent material (PM) used in this work was AA2014 sheet of 2 mm thick with dimensions of 300 long and 150 mm wide. The properties of PM are listed in Table 1 and Table 2 respectively. Fig.1a showed the microstructure of BM, it consists of varying grain size which is oriented along the processing direction. The samples were longitudinally butt welded using CNC friction stir welding machine. Fabricate non-consumable tool consist of a plain concave shoulder with the left hand threaded to taper cylindrical pin (Fig.1b). The process parameters which were used in this investigation is tabulated (Table 3). After weld (Fig.1c), the joints were cut perpendicular to the processed direction (Fig.1d). Metallography observation was carried out by an OM. The specimens were polished with alumina suspension etched suitable etchant for structure. The size of composite tensile specimens was prepared by the reference to the ASTM-E8-M04. Tensile test was carried out with a velocity of 1.5 mm/min. The hardness survey was done across the weld with a constant load of 0.05 N and dwell time of 15 s. SEM used to reveal the fracture morphology of the joints.

Revised Manuscript Received on 05 February 2019.
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Table. 1 Chemical properties (wt. %) of the PM

Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
0.8	0.1	4.8	0.8	0.7	0.06	0.005	0.011	Bal

Table. 2 Mechanical properties of PM

Material	Y.S (MPa)	UTS “MPa”	(%)	Vicker hardness 0.5 N, 15 sec (HV)
Al	435	456	9.8	160

III. RESULTS

Surface morphology

The surface morphology of the friction stir welded (FSWed) joints under different welding conditions using predominant welding parameter is welding speed (Fig.2). The joint fabricated using a TRS of 1500 rpm, WS of 50 mm/min, SD of 6 mm and TA of 1.5º exhibited higher strength with their other joints. Also, the surfaces of all the joints are smooth. The joint made up with the various WS is presented in Fig.2, it could be noted that severe plastic deformation was found at a low WS of 10 mm/min due to more thermal energy, as it results in warm hole defect. At higher WS of 70 mm/min, the surface was covered slight delamination and lack of filling the defect, because, the contact time of the shoulder and the sheet was low and heat input is negative effect to the WS [13]. Hence, testing of these two joints was not carried out for further investigation.

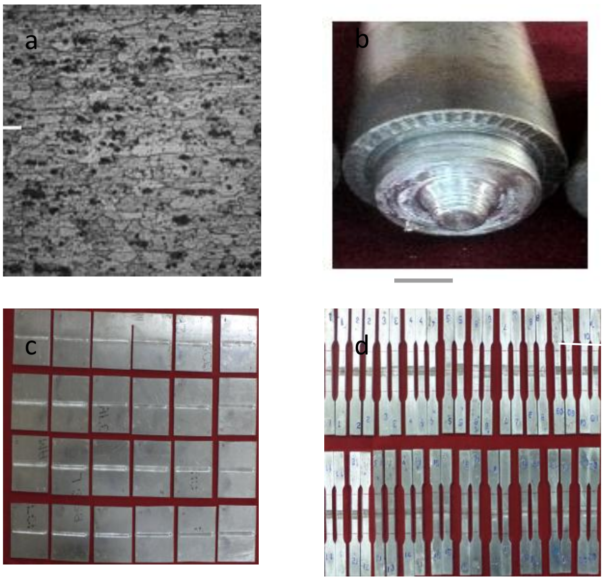

Fig. 1 a) Optical micrograph of PM, b) Used FSW tool, Photograph of c) fabricated joints and d) Tensile specimens

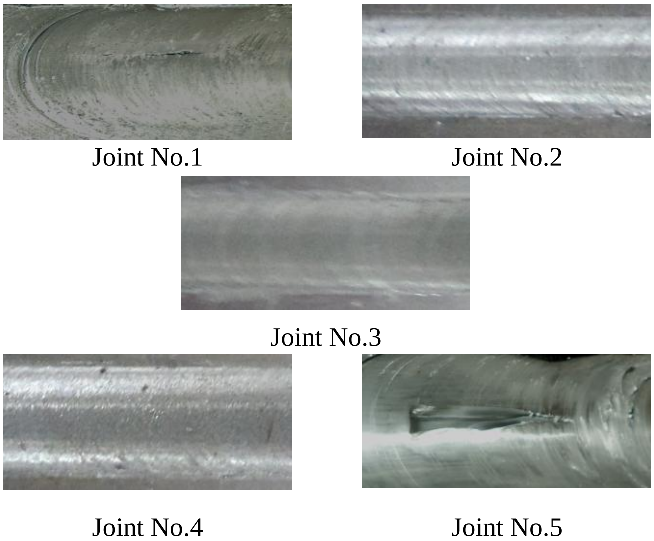

Fig. 2 Effect of WS on weld surface

Mechanical properties

Tensile properties of FSWed were quantified by conducting a tensile test of transverse specimens. Table 3 revealedstrength data of FSWed joints under different processing parameters. It is evident from the Table 3 that the YS, UTS and elongation of FSWeld are inferior to the PM. At the constant TRS of 1500 rpm, SD of 6 mm and TA of 1.5, an increasing WS of 20 mm/min to 40 mm/min almost linearly increased to UTS, YS, elongation of 381 MPa, 279 MPa and 5.8 % respectively. Further, decreased with increasing the welding speed of 60 mm/min. From the Fig.3. Many microhardness profiles should be placed in evidence against the effect of FSW parameters. Fig.4 shows the microhardness distribution of transverse cross-section of the weld under different processing parameters. The joint exhibited typical W shaped hardness profiles.

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The hardness of the FSW joints (average of 101 HV -134 HV) was lower than the base material (155 HV). The hardness of SZ was higher than the TMAZ and can reach BM hardness level. It could indicate that the hardness of SZ was great dependence on FSW parameters.

Table. 3 Effect of FSW parameters on strength

Joint No	Cond.	Parameters		Hardness	Elongation (%)	YS “MPa”	UTS	Efficieny “%”
1	Welding speed “mm/min”	10	1500 rpm 6 mm 1.5º	101	3.2	174	208	46
2		20		121	4.9	185	239	52
3		40		130	5.8	279	381	83
4		60		125	4.1	201	261	58
5		70		109	3.3	156	210	47

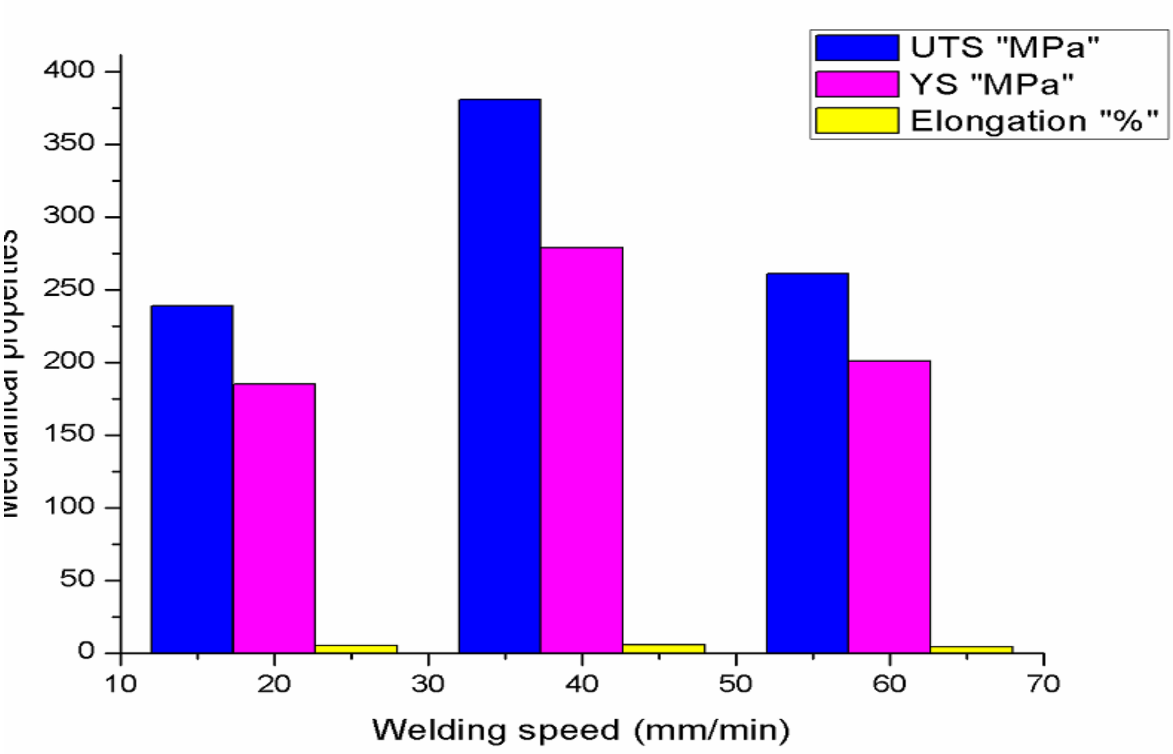

Fig. 3 Effect of WS on strength

Two primary reasons for enriched the SZ hardness, first one is the formation of subgrains (fine grains) due to dynamic recrystallization (DRX) and the second one, the density distribution of precipitates during FSW. Each joint had two soft regions (low hardness region), one on the AS and another on the RS. The location of the soft region was obviously different from irrespective of process parameters. The hardnessin SZ developed from 121 HV to 130 HV, 126 HV to 131 HV and 126 HV to 134 HV, while increasing WS of 20 mm /min to 40 mm/min and SD from 4 mm to 6 mm respectively. And decreased to 125 HV, 128 HV, and 125 HV, while increasing to WS of 60 mm/min and SD of 8 mm respectively.

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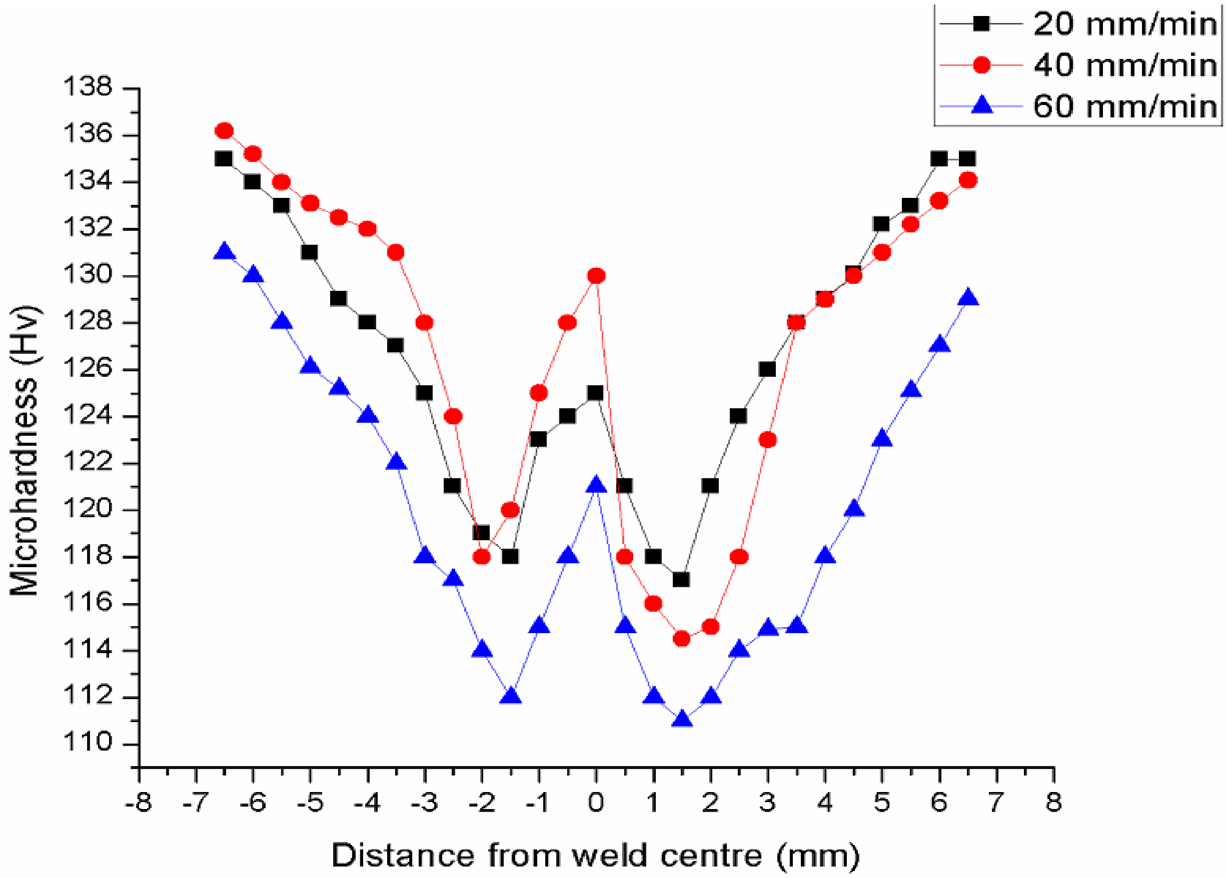
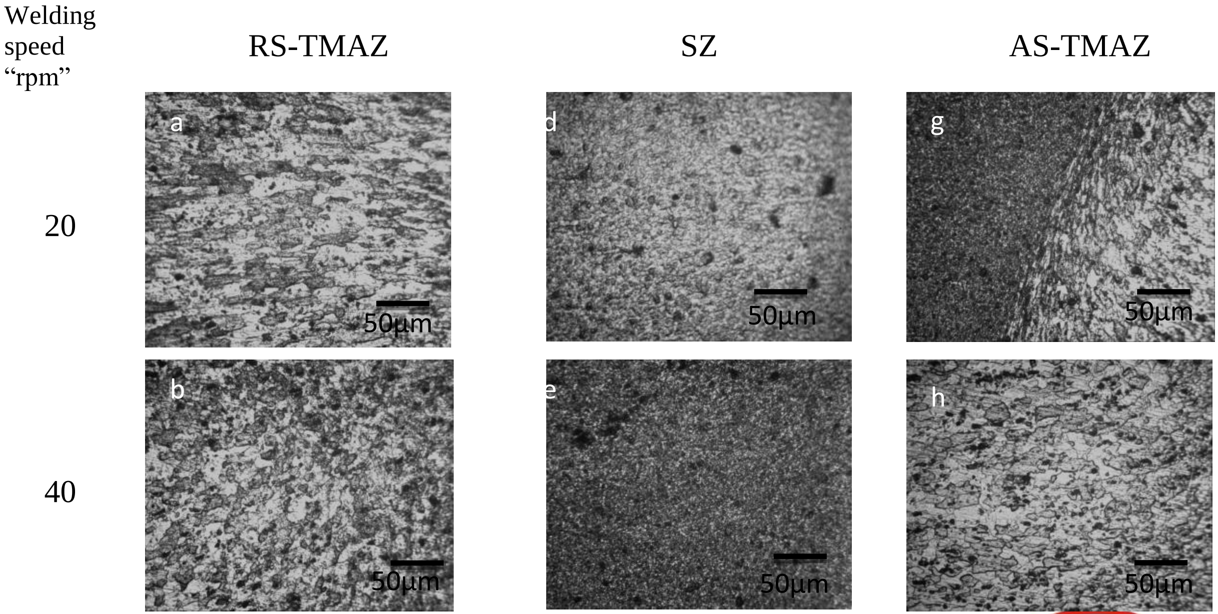


Fig. 4 Effect of WS on hardness

Microstructure

Fig.5 showed the set of figures related to the optical micrograph effect of WS on FSWed joints. Based on the material flow and grain sizes, the joints were classified into three regions such as the SZ, TMAZ and PM. The SZ microstructure is characterized by recrystallized, fine and equi-axed grains. A complex flow structure consists of upward elongated grains, was observed in the TMAZ on both RS (Figs. 5 a-c) and AS (Fig 5 e-i), on the other hand, unaffected BM. All the SZ invariably contains fine and equi-axed grains (Fig 5 d-f). Because of plastic properties and high temperature to causes DRX, caused by motion of tool during FSW. The large and elongated grains converted into fine and equi-axed grains in the SZ. Similarly, the increase in WS decreases the average grain size of SZ (8.9 µm), due to the low level of heat and allows its faster cooling rate and prevents grain coarsening [15].



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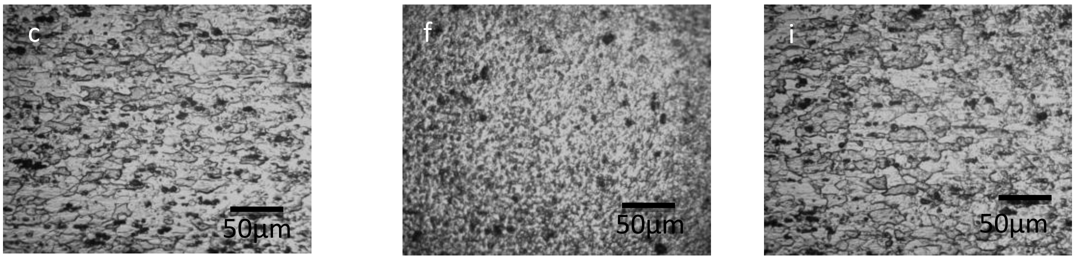

Fig. 5 Effect of welding speed on microstructure

IV. DISCUSSION

Table 4 enlisted the FSW parameters on the fracture morphology of FSWed joints under different parameters. During FSW, the strength of joint was closely linked to the flow of material in and around the tool pin. Based on the material flow in the SZ, was classified into three states such as "insufficient, balance and excessive material flow [16,17]. The optimum level of material flow state can be obtained by choosing a proper combination of process parameters. The excessive and insufficient material flows were easily produced defects. It is attributed due to heat input [21]. The rate of heat generation of the heat energy during FSW is a function of WS [18]. Fine eutectic element of Cu in aluminum alloy is dissolved and uniformly strewn in the α- aluminum matrix. The rate of heat dissipation in the thermal cycle retains this solute in the aluminum matrix. Of the five things, the joint formed using a WS of 40 mm/minyielded higher strength than others. Due to the defect-free and sound joints. Moreover, the formation of a Cu element distributed over the Al. At low WS (10 mm/min), the joint consists of coarse Cu particle reduces the strength. The joint at higher WS of 70 mm/min consists of a channel-like defect in the RS of the SZ, due to insufficient flow state and consist of coarse grains. The reason for peak strength was achieved by the joint formed using a WS of 40 mm/min (under constant TRS of 1500 rpm, SD of 6 mm TS of 1.5), the optimum heat input creates balanced material flow state and density distribution of precipitates (Al2Cu) in the SZ. From the Table 4, it is understood that the parameters had a significant effect on the fracture pattern of the FSWed joints.

The fractured surface of the welds invariably showed dimples of erratic size and form separated from scratch edges. Which an indication of ductile failure [19] apart some low input joints produced high WS (60 mm/min) and small SD (4 mm). Failure pattern was brittle in low heat input joints and fracture surface concealed with ridges. At the high heat input showed ductile fracture mode with large and elongated dimples.

V. CONCLUSION

The following conclusions can be obtained from this investigation.

1. The sound welded joint was obtained at the tool TRS of 1500 rpm, WS of 40 mm/min, SD of 6 mm and TA of 1.5º. It could be due to the balanced material flow around the pin with optimum heat input.
2. The increase in solute concentration in the SZ due to optimal heat input, which enhanced tensile properties of the joint.
3. The hardness distribution is in good agreement with the obtained microstructure and shows two soft regions on both the side of each joint.

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