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Effect of Skewness during Friction Stir Welding of Dissimilar Aluminium Alloys EN AA 5083-H116 and EN AA 6082-T6 Including Fracture Observations

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Abstract: The corrosive resistant aluminium-magnesium alloy AA 5083-H116 and aluminium-silicon alloy AA 6082-T6 is widely used in ship building, marine and various structural applications. FSW is an emerging solid state joining process suitable for joining the aluminium alloys with minimized formation of weld defects like cracks, porosity etc. compared to other fusion welding processes. This research work presents FSW of EN AA 5083-H116 and EN AA 6082-T6 using skew tool pin profile with the consideration of influential process parameters like tool rotational speed of 710 and 900 rpm at constant traverse speed of 16 mm/min. Radiographic inspection has been performed for evaluating the weldments soundness. From the radiographic results it has been found that at higher rpm i.e at 900 rpm the occurrence of lack of fusion is more compared to the weldment fabricated at 710 rpm. Tensile properties and fractural observations were carried out on the weldments. It has been noted that good mechanical properties were observed with the weldment fabricated at 710 rpm with high tensile strength of 160 MPa. From the fractural observations it has been observed that all the specimens are prone to ductile fracture, besides shear lips were observed at specimens fabricated at 900 rpm.

Keywords: FSW, Skew tool pin profile, Mechanical properties, Fracture.

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I. INTRODUCTION

High Strength AA5083-H116 (Al-Mg-Mn) and medium strength AA6082-T6 (Al-Si-Mg) finds wide range of applications in shipbuilding, automotive industries due to excellent coupling of corrosion with workability and ease of weldability [1].

Joining two dissimilar materials leads to combination of material properties of both two materials which in turn makes the joined weldments favourable for military based applications like light weight tanks, military bridges, battle tanks, armour protected ambulance, titanium light weight howitzers, layer tanks etc. Aluminium alloys are mainly employed for fusion based welding techniques. However, fusion based welding imposes great provocation because of change in alloy composition, thermal properties and other mechanical and metallurgical properties. In extension, the complication related to weld solidification like formation of cracks, undercuts, porosity etc. decrease the weldment quality leading to formation of large coarse grains and intermetallic compounds at the weld area leading to decrease in mechanical properties.

Friction Stir Welding (FSW) is a solid-state welding process where two adjacent materials are joined by means non-consumable rotating tool thereby melting and plasticization of the weld affected zone occurs then the solidified material is made to move across the weldline. In the FSW process the development of brittle products can be minimized and grain boundaries crack formation and over liquification can be erased. Many reactions that are developed during the metallurgical examination of two dissimilar metals particularly at higher temperature elevation can be eliminated. Thereby FSW is the only welding process that has the ability to join materials having incompatibility. The formation of weldment is entirely based upon behaviour and flow of the material. In FSW, the generation of heat is due to rubbing caused by the tool pin profile on the base material leading to the formation plasticized material around the weldline. The tool pin probe has a notable effect on rubbing action of the tool which thereby responsible for generation of plasticized material.

The ratio of swept to dynamic volume plays a crucial role in the formation weldment thereby deciding the flow of material around the weldline. The base material has to be swirled by taking process parameters like tool rotational speed and has to move with desired weld traversing speed in order to obtain the weldments that are free from defects. In order to eliminate the defects skew tool pin profile has been employed for fabricating the weldments having good material characteristics such as orbital forging action, high material mixing and reduction in TMAZ, HAZ regions, etc. Very few experimental investigations are carried by employing skew pin profile on mechanical and fractural locations on the failure area of the weldments [2]. Sarath et.al [4] performed optimization of weld process parameters on AA5083 and AA 6082 with process parameters like tool rotational speeds 700, 900 and 1100 rpms, weld traverse speeds 70, 90 and 110 mm/min and 0, 1 and 2^0 tool tilt angle using threaded tool pin profile and concluded high tensile strength of 217 MPa was obtained at optimized values 700 rpm, 110 mm/min and 2^0 respectively. Shiva et.al [5] performed FSW on AA5083 and AA6061 using taper threaded tool pin profile with process parameters like tool rotational speeds 710, 900 and 1400 rpm's and weld traverse speed 40 mm/min and concluded high mechanical properties and hardness was obtained at 900 rpm. Yeswanth et.al [6] performed optimization of AA5083 and AA6082 using circular and square tool pin profile with process parameters like tool rotational speeds 710, 1000 and 1400 rpm's and weld traverse speed 20 mm/min and concluded that defect free sound joint was obtained at 1000 rpm at 20 mm/min respectively.

In the present research work, the effect of skew pin profile on mechanical properties were studied thereby examination of fracture occurred on the failure locations were investigated. The below Fig. 1 shows the basic FSW performed on the materials.

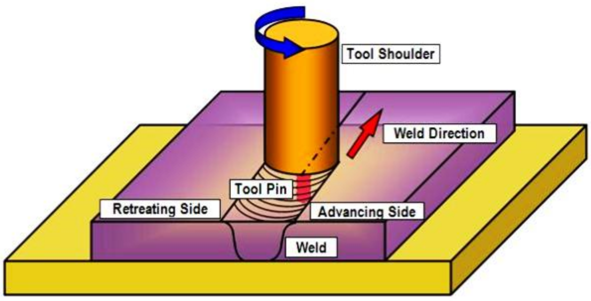

Fig. 1. FSW of butt joints [3]

II. EXPERIMENTAL WORK

6 mm thick hot rolled plates of EN AA 5083-H116 and EN AA 6082-T6 aluminium alloys was shear cut and milled into required size of (200 mm × 80 mm). Chemical composition and mechanical properties of base materials were shown in Tables 1 and 2 respectively. HMT make VMM has been employed for performing FSW on the dissimilar materials AA 5083-H116 and AA 6082-T6 aluminium alloys is shown in Fig. 2. Infrared thermometer has been employed in order to note down the temperature developments along the weldments as shown in Fig. 3. Design and fabricated of Skew tool pin profile which is used is for fabricating weldments shown in Fig. 4 and 5. Welding process parameters like tool rotational speeds 710 and 900 rpm's and 16 mm/min traverse speed are taken into account for performing FSW.

Table - 1. Chemical composition (wt%) of AA 5083-H116 and AA 6082-T6

Alloys	Mg	Mn	Si	Fe	Cu	Zn	Cr	Cu	Al
AA 5083-H116	4.9	1.0	0.4	0.4	0.1	0.25	0.25	0.1	95.6
AA 6082-T6	0.7	0.5	1.02	0.29	0.01	0.02	0.011	0.014	97.23

Table - 2. Mechanical properties of AA 5083-H116 and AA 6082-T6

Alloy	0.2% Y.S MPa	UTS/MPa	% El
AA 5083-H116	215	305	16
AA 6082-T6	250	290	10

Fig.2 HMT 3-Axis VMM

Fig. 3. Infrared Thermometer employed for measuring temperatures across the weldments

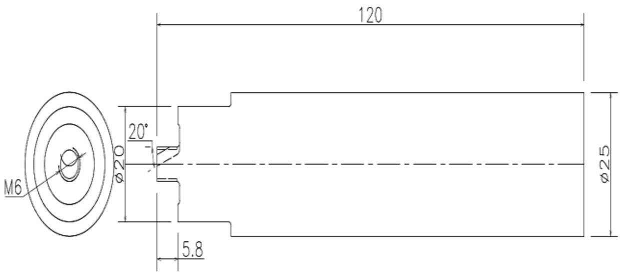

Fig. 4. Design of skew tool pin profile

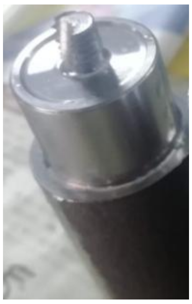

Fig. 5. Hardened Skew tool pin profile

The weldments fabricated using skew tool pin profile on AA 5083-H116 and AA 6082-T6 aluminium alloys with weld process parameters like tool rotational speed 710 rpm and 900 rpm at constant weld traverse speed of 16 mm/min are shown in Fig. 6 and 7 respectively.

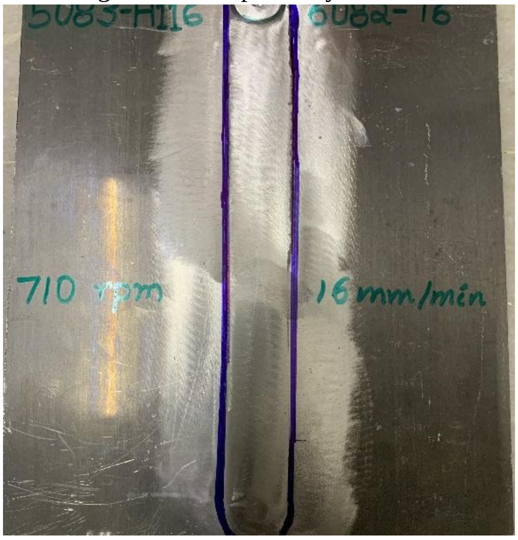

Fig. 6. Weldment fabricted at 710 rpm

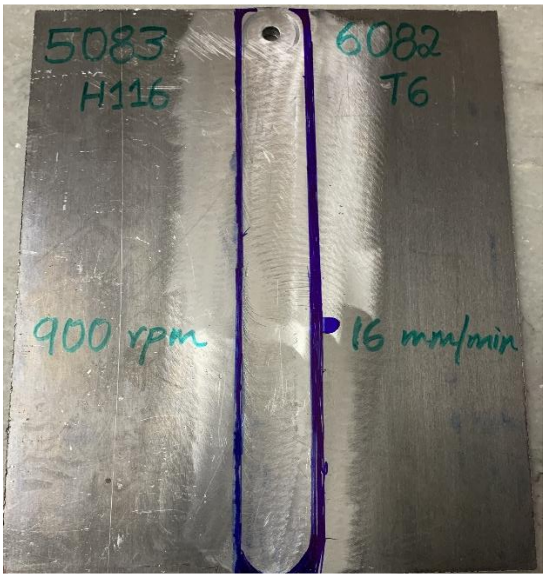

Fig. 7. Weldment fabricted at 900 rpm

III. RESULTS AND DISCUSSIONS

X-ray radiography has been employed on the weldments and from the x-ray films the following observations were made:

1. Weldment produced at 710 rpm showed lack of fusion upto 140 mm from the hole end and the remaining 60 mm length defect free weld was obtained.
2. Weldment produced at 900 rpm showed lack of fusion upto 200 mm.

Lack of fusion on the weldments was observed due improper stirring of base material round the weld zone. Besides at 900 rpm excessive flash was observed due to excess generation of heat around the weld zone.

Tensile test was performed as per ASTM B 557:2015. TEC make FE 211 electro mechanically controlled universal testing machine employed for tensile testing is shown in Fig. 8. Design of ASTM E8M-04 tensile specimen is shown in Fig. 9. Specimens are extracted from the weldments according gto ASTM E8M-04 standard at 710 and 900 rpms are shown in Fig. 10 and 11 respectively.

Fig. 8. UTM machine

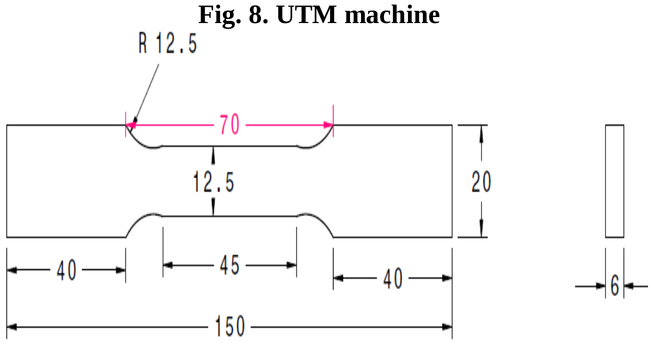

Fig. 9. Design of tensile specimen as per the ASTM E8M-04 standard

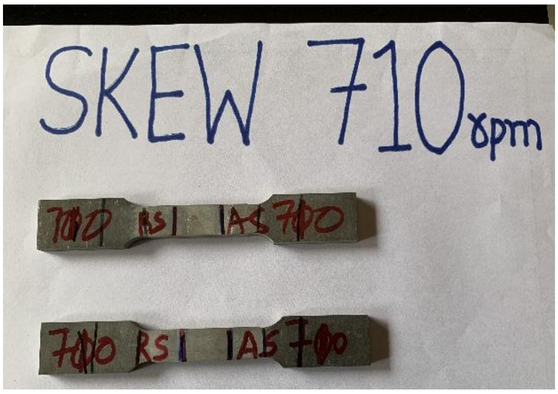

Fig. 10. Dissimilar Aluminium Alloys Tensile specimens at 710 rpm

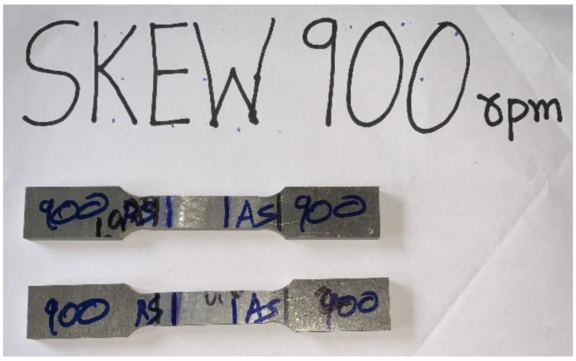

Fig. 11. Dissimilar Aluminium Alloys Tensile specimens at 900 rpm

The average of tensile results of weldments fabricared at 710 and 900 rpm and failure locations are presented in Table - 3.

Table. 3 Average tensile results and zone of failure

Weld parmeters	UTS MPa	0.2% Y.S MPa	% El	Failure location	Failure zone
710 rpm	160.46	154.46	10.2		RS-TMAZ
900 rpm	156.26	138.4	8		Weld Zone

The below Fig. 12 and 13 shows fracture occured on the tensile tested specimens performed at tool rotational speed 710 rpm and weld tarverse speed of 16 mm/min.

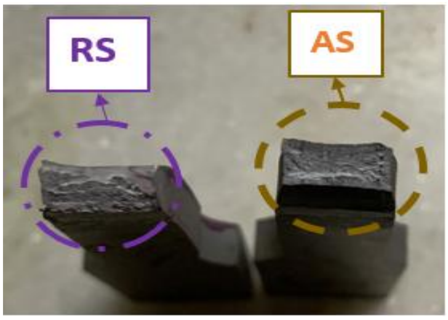

Fig. 12. Specimen -1 fracture occurred at 710 rpm

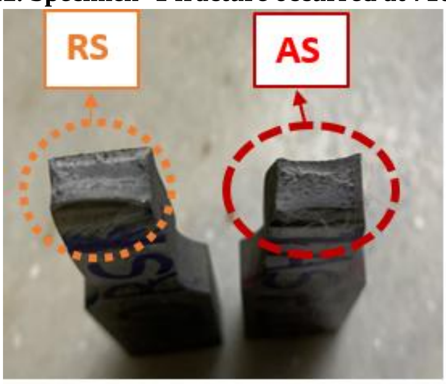

Fig. 13. Specimen -2 fracture occurred at 710 rpm

In specimen – 1 fracture on AS (Advancing Side) ~ 45^0 shear lip, kissing bonds on the ends of fractured specimen with coarse grains and riverlike patterns and dimples. Shear lip was observed due to improper mixing of dissolved strengthened particle and localized stress occurred during tensile test. Besides kissing bonds, riverlike patterns and dimples are formed due to insufficient heat input, shoulder pressure leading to the formation of coalescence along the fracture path. On RS (Retreating Side) sharp tearing ridges, stirations and slight blunting edges are observed due void nucleation, agglomeration of grain conglomerates leads to formation of stirations and excess localized causes formation of blunt edges. In Specimen-2 fracture on AS and RS of the tensile tested specimens contains ~ 45^0 shear lip with river like patterns, shallow dimples, blunt edges and ratchet marks. Ratchet marks are formed mainly due to high local stress concentration and low shoulder pressure during welding. The below Fig. 14 and 15 shows fracture occured on the tensile tested specimens performed at tool rotational speed 900 rpm and weld tarverse speed of 16 mm/min.

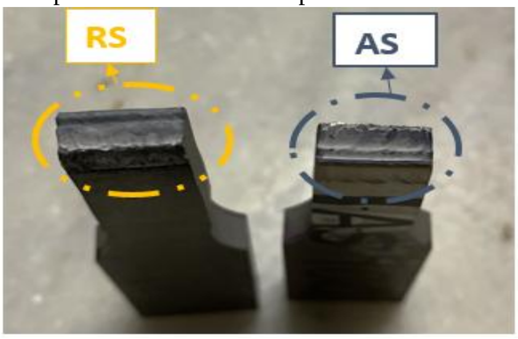

Fig. 14. Specimen -1 fracture occurred at 900 rpm

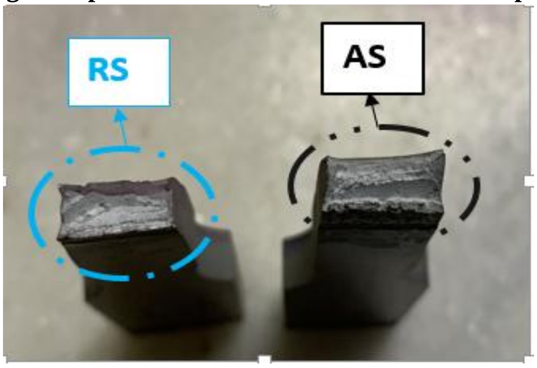

Fig. 15. Specimen -2 fracture occurred at 900 rpm

In specimen - 1 at 900 rpm cup-cone fracture was observed on both AS and RS with clamshell patterns and rupture. Clamshell marks were formed due to interruptions during the crack propagation stage. In specimen - 2 at 900 rpm cup-cone fracture was observed on both AS and RS with sharp tearing ridges, blunt edges and wavy river like patterns on the failure locations. These type of fracture was encountered due high tool rotational speed, excess fatigue generation occurred while performing tensile test [7].

IV CONCLUSIONS

- At lower rpm (710 rpm) the lack of fusion was formed up to 140 mm length besides surfaces defects like flash and burrs are eliminated.
- At high rpm (900 rpm) entire weldment produced lack of fusion leading to generation of high temperatures (250^0 C) thereby leading to formation of excessive flash and burrs around the weld zone.

- High UTS of 160.46 MPa, 0.2% Y.S 154.46 MPa and % EL of 10.2 was obatined with weldment fabricated at 710 rpm and 16 mm/min.
- Ductile fracture was observed in all the tensile tested specimens shear lips are observed mainly at higher rpm's i.e at 900 rpm.

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