PANTHAKI MEMORIAL AWARD

Mechanical Properties and Microstructural Evolution in Al-Cu-Li 2195 Alloy GTA and FSW Welds

Agilan M[a,b*], Gandham Phanikumar[b], D Sivakumar[a]

Materials & Metallurgy Group, Vikram Sarabhai Space Centre, ISRO, Trivandrum,
India Indian Institute of Technology Madras, Chennai - 600 032, India
*E-mail : agilan103@gmail.com

DOI : 10.22486/iwj/2019/v52/i4/186789

ABSTRACT

Aerospace and launch vehicles structures demands materials with low density and high strength. 2195 is an advanced Al-Cu-Li alloy, considered as a potential material for launch vehicle structures due to low density and high strength. However, the fusion weldability of this alloy is not as simple as conventional 2219 alloy. Porosity and solidification cracking are main concerns in 2195 alloy with respect to weldability. In this present work, weldability issues are addressed to minimise their effect. 2195 alloy is welded by gas tungsten arc welding (GTAW) and friction stir welding (FSW) using optimised process parameters. Weld tensile properties of GTA and FSW welds were evaluated in as-weld condition. Hardness survey across the welds was performed. Microstructural analysis of GTA and FSW welds were carried out. Effect of tool rotation speed and tool travel speed on mechanical properties was studied.

Keywords: 2195 alloy; Gas tungsten arc welding (GTAW); Friction stir welding (FSW); Weldability.

1.0 INTRODUCTION

Currently, propellant tanks of space launchers are made of 2219 Al-Cu alloy and fabricated by Gas Tungsten Arc Welding (GTAW) process. Al-Cu-Li alloy, equivalent to 2195 is a potential alloy to replace 2219 due to high strength, elastic modulus and low density. Replacement of 2219 propellant tanks by 2195 alloy can produce significant payload gain in space launch vehicle. However, the presence of Li in 2195 makes the alloy hygroscopic and produces porosity in the fusion welds [1]. In addition, the hot cracking resistance of Li containing aluminium alloys is inferior to 2219 [2]. These weldability issues limit the alloy to be welded by fusion welding processes. Friction stir welding (FSW) is a promising solid state joining process which prevents the defects produced in fusion welding. In FSW process, the base metal is brought to plastic state where the temperature is less than melting point, subsequently mechanically stir the base metal together under the axial pressure to form weld joint.

To exploit 2195 in various launch vehicle structures, it is necessary to understand the effect of process and parameters on mechanical properties and microstructure evolution of welds. In this present work conventional 2219 alloy and superior 2195 alloy are welded by GTAW and FSW process and compared.

2.0 EXPERIMENTAL DETAILS

Achieved chemical composition of 2219 and 2195 alloys are given in **Table 1**. To take advantage of high strength, base metals used in this study are welded in T8 temper condition. Thickness of base metal for GTAW and FSW are 4 and 5 mm respectively.

Table 1 : Chemical composition of 2219 and 2195 alloy in weight %

Alloy	Cu	Li	Mg	Mn	Zr	Ti	Ag
2219-T8	5.9	-	-	0.27	0.1	0.06	-
2195-T8	3.8	1.1	0.33	0.1	0.18		0.4

GTAW was done using AMET make fully automated welding machine with rated output of 450A at 40V DC. The welding was done in alternate current (AC) welding mode using 2319 filler wire. Weld parameters are 200 A, 7 V and 250 mm/min, the calculated heat input was 336 J/mm. Optimized GTAW parameters produced in full penetration weld with good reinforcement.

FSW was performed in ETA make machine, where the weld coupons are held in fixture and tool moves in horizontal position and produce the welds. A plain frustum cone shaped tool made up of H13 tool steel material was used in this study. The shoulder was made flat with 20 mm diameter and the pin diameter was 6 mm at the top and 4 mm at the bottom with 4.8 mm pin length. Tool travel was across rolling direction i.e., welds were oriented normal to rolling direction. FSW parameters such as tool rotation speed and travel speed were optimized. Defect free welds were produced with 300 mm/min travel speed and 600 rpm tool rotation speed.

GTAW and FSW weld coupons were subjected to visual inspection, penetrant test and radiographic testing. Weld coupons were cut transverse to the welding direction using abrasive cutting machine for characterization. Optical micrographs were taken using Carl Zeiss, Axio Lab A1 inverted microscope. Base material and weld cross-section were cut, mounted, polished and chemically etched using Keller's reagent to reveal the microstructure. Vickers hardness measurements were made on base material and weld cross section using Q-ness Austria make micro hardness testing machine with 500 gram load. Base metal and transverse weld tensile specimens were fabricated with 25 mm gage length and 6.25 mm gage width. Tensile testing was conducted on a 2000 kN Instron make servo hydraulic universal testing machine with constant crosshead speed of 0.1 mm/min.

3.0 RESULTS AND DISCUSSION

3.1 Base Material Characterization

Microstructure of both 2219 and 2195 alloy depict typical rolled structure of elongated grains. Tensile properties of base materials are shown in **Table 4**. 2219 tensile properties at T87 temper condition was measured as 489 MPa of ultimate tensile strength (UTS), 397 MPa of yield strength (YS) and 12.3 % elongation. For 2195-T8 alloy, the values were 560 MPa of UTS, 522 MPa of YS and 14.8% elongation. There were significant difference in strength values observed between 2219 and 2195 alloy. Increase in ultimate tensile strength (UTS) and yield strength (YS) were 15% and 31% respectively. Generally in heat treatable aluminum alloys, type of strengthening precipitates formed during aging determine the final strength.

In 2219, primary strengthening precipitate is by θ′ (Al_2Cu) whereas 2195 is mainly strengthened by T1 (Al_2CuLi) and θ′ (Al_2Cu). Base material hardness for 2219 was measured as 148-152 HV0.5 and 2195 was in the range of 169-173 HV0.5

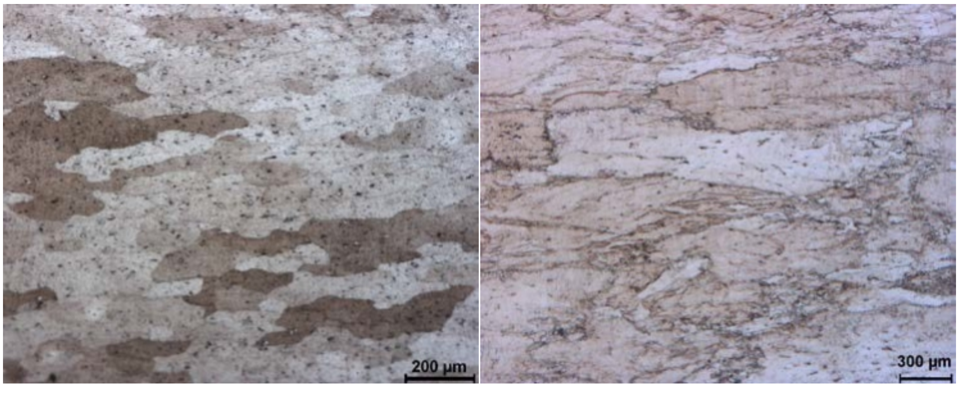

Fig. 1 : Base material microstructure of a : 2219 and 2195 alloy

Table 2 : Tensile properties of 2219 and 2195 base metal

Material	UTS (MPa)	0.2% YS (MPa)	% Elongation
2219-T8	489	397	12.3
2195-T8	560	522	14.8

3.2 Evolution of Microstructure in GTAW and FSW Welds

Microstructure evolution in GTA and FSW welds of 2219 and 2195 alloys are shown in **Fig. 2**. In GTAW, welds were made with complete fusion and full penetration with good reinforcement. The weld fusion zone was characterized by dendritic structure, a typical weld cast microstructure. The dendrites grew as columnar grains from the base metal and ended as equi-axed grain at the weld centre. Fine recrystallized chill grains were observed at the weld interface. The size and morphology of the dendrites is controlled by the weld metal cooling rate. When the weld metal cools fast, the interdentritic spacing is small, and vice versa.

In FSW, Weld nugget zones reveal fine, recrstallized, equiaxed grains with average grain size of 20 µm. This is due to the influence of high temperature and severe plastic deformation. The grain size in the nugget region varied across the thickness. It was observed that coarse grains at the top and fine grains at the bottom. Due to shoulder pressure and action, heat input was expected to be more at the top and the backing plate kept at bottom took away the heat from work piece. Low input and fast cooling rate at the bottom produced fine grains.

In thermo mechanical affected zone (TMAZ), the grain alignment was elongated and distorted due to thermo-mechanical processing whereas HAZ was not subjected to any plastic deformation however temperature influence was present as revealed in hardness test.

3.3 Mechanical Properties of 2219 And 2195 Welds

During GTA welding the abutting surfaces melts and solidifies, whereas in FSW, joining occurs by mechanical and thermal effects without melting. Because of solidified cast structure in GTA weld, prior temper condition is completely lost. Therefore, degradation in mechanical properties is expected. Conversely, properties of FSW welds are conserved to a large extent due to solid state joining.

Ultimate tensile strength (UTS) of base metal, GTA and FSW welds of 2219 and 2195 alloys are shown in **Fig. 3**. It was noticed that there was 40-50% reduction in

UTS of GTA welds. Weld efficiency for GTA weld for 2219 and 2195 was calculated as 51% and 55% respectively. However, 2195 GTA weld showed 57 MPa higher UTS than 2219 weld. It was due to presence of additional alloying elements like Ag, Li, Mg, Zn and Zr in 2195 which act as solid solution strengtheners.

In case of FSW, Weld efficiency with respect to UTS was 70% in both 2219 and 2195 welds. In age hardenable aluminum alloy, mechanical properties of FSW joint mainly depend on amount, size and distribution of precipitates and they are marginally influenced by grain size in the nugget zone and residual stress produced during welding [10]. The degradation in properties in FSW was due to coarsening and dissolution of strengthening precipitates as the influence of temperature. 2195 showed 47 MPa higher strength than 2219 due to aforesaid reason in GTAW.

0.2% yield strength (YS) of base metal, GTA and FSW welds of 2219 and 2195 alloys are shown in **Fig. 4**. In both GTAW and FSW, percentage of reduction in YS with respect to base metal was higher than UTS. Although as-cast structure in GTAW and dissolution of precipitates brought down the properties, the presence alloying elements conserve the UTS to smaller extent by solid solution strengthening.

% Elongation of base metal, GTA and FSW welds of 2219 and 2195 alloys are shown in **Fig. 5**. In weld specimens, the gage length marked for measurement of uniform elongation composed of weld zone, HAZ and TMAZ (only in FSW). Measured elongation was an average strain from these regions. There was about 50% reduction in ductility after GTAW welding, because the plastic deformation was obstructed by as-cast structure. In case of FSW, decrease in ductility was due to fine recrytallized grains and loss of base metal temper condition. Nevertheless, ductility of FSW in both 2219 and 2195 alloys was higher than GTAW. In both GTAW and FSW, location of failure after tensile test was weld region.

3.4 Fractogrpahy Anaysis of 2195 Base Metal and Welds

After tensile test, fractured surfaces of 2195 base metal, GTAW and FSW weld specimens were analyzed in scanning electron microscope. Fractographs are shown in **Fig. 6**. Base metal showed dimple features throughout the fractured surface, it confirmed that the material possessed excellent ductility in as-received condition. Dendritic features are clearly visible in GTAW specimen, the reduction in ductility was due to fracture

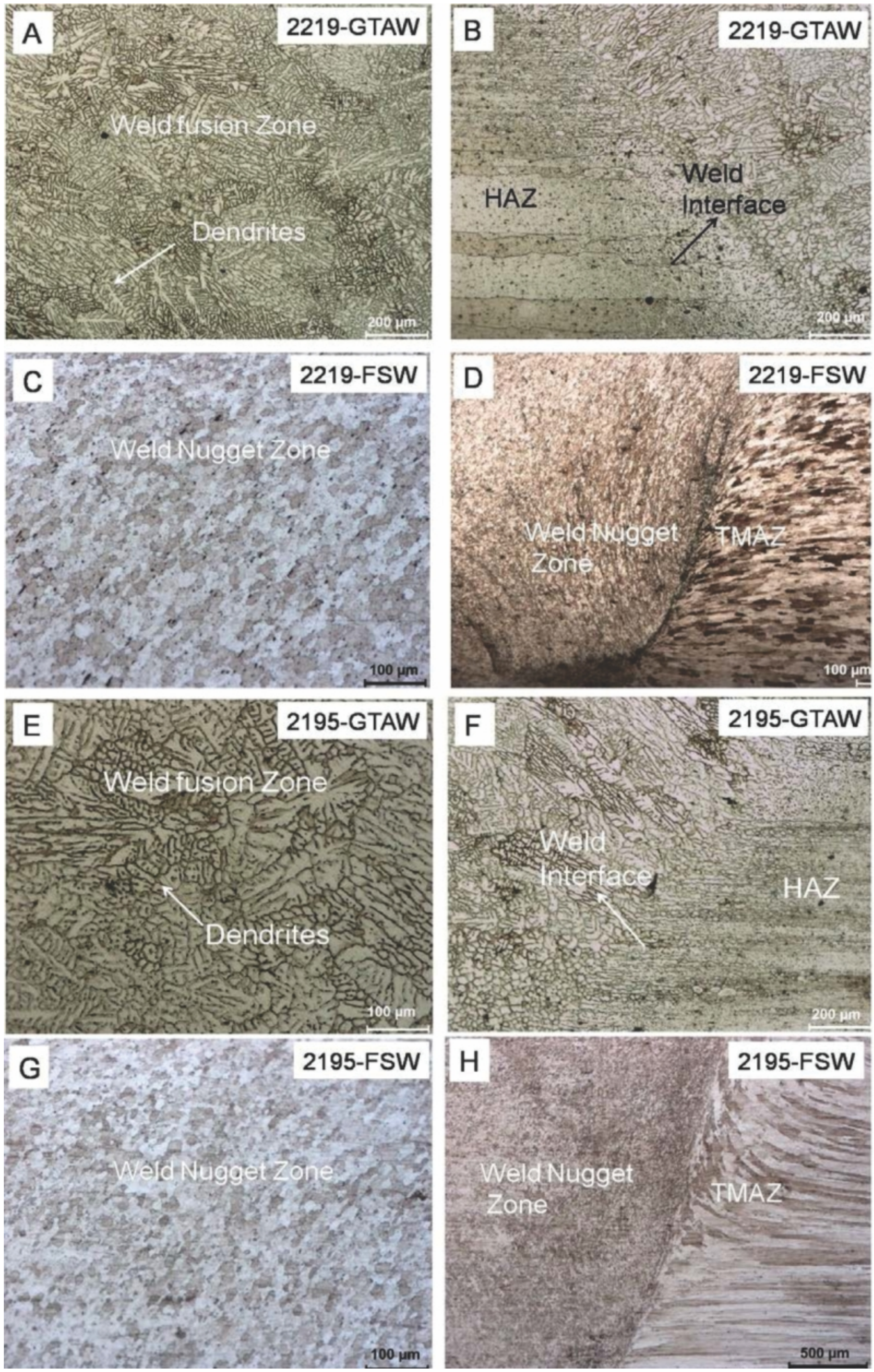

Fig. 2 : Weld microstrucutres A) and B) 2219-GTA weld, C) and D) 2219-FSW weld E) and F) 2195-GTA weld G) and H) 2195-FSW weld

along the dendritic arms. FSW specimens showed micro-dimples on the fracture surface, it confirmed that the failure was in fine recrystallized region of nugget zone.

3.5 Microhardness Survey Across 2219 and 2195 Welds

Microhardness measurements were taken across the GTAW and FSW joints of 2219 and 2195 alloy and shown in **Fig. 7**. Hardness values from base material decreased gradually through heat affected zone (HAZ) and reached minimum at weld zone. In all the conditions, lowest hardness was observed in weld region, therefore tensile specimens failed at the centre of weld. Hardness profile across the welds indicated comparable trend with tensile properties of base metal and of weld joints.

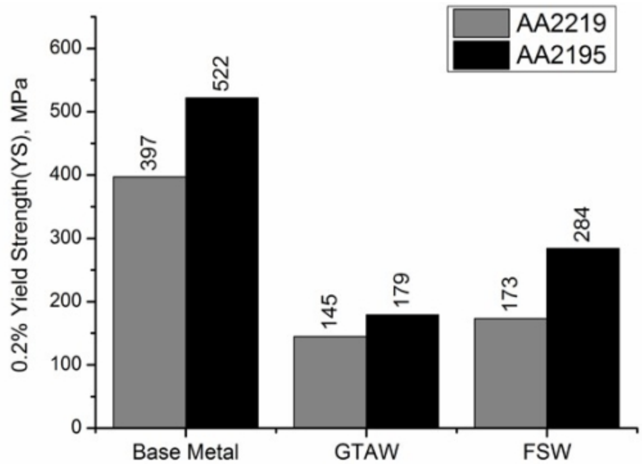

Fig. 4 : Yield strength of BM, GTAW and FSW of 2219 & 2195 alloy

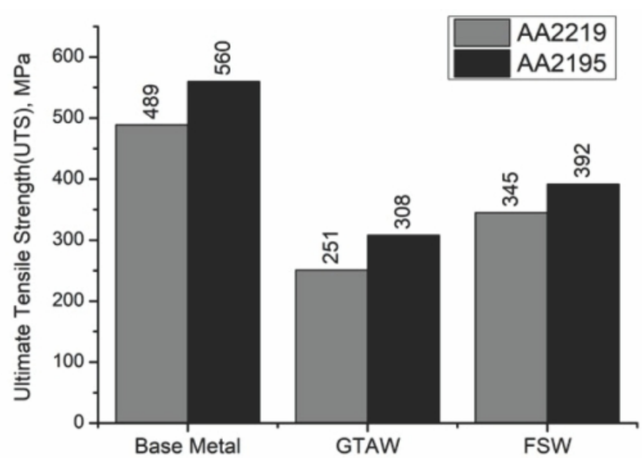

Fig. 3 : Ultimate tensile strength of BM, GTAW and FSW of 2219 & 2195 alloy

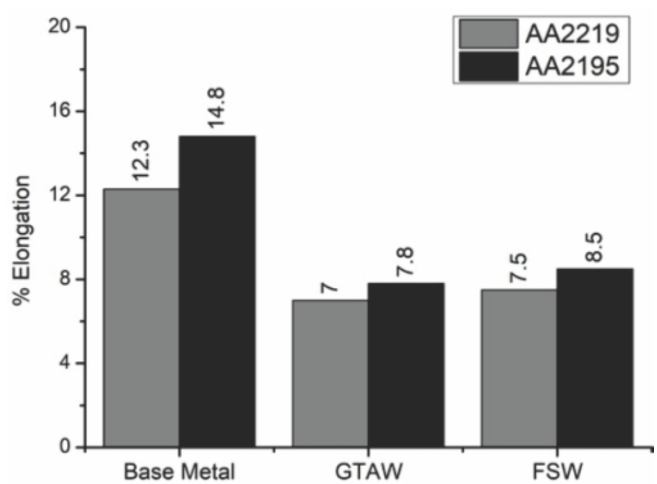

Fig. 5 : % Elongation of BM, GTAW and FSW of 2219 & 2195 alloy

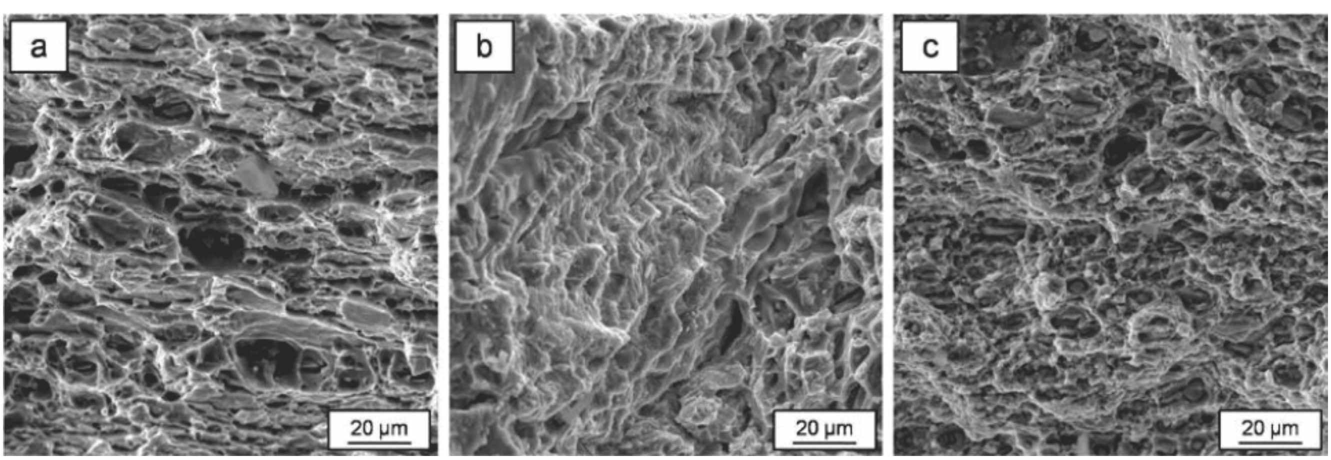

Fig. 6 : Fractographs of a) BM, b) GTAW and c) FSW of 2195 alloy

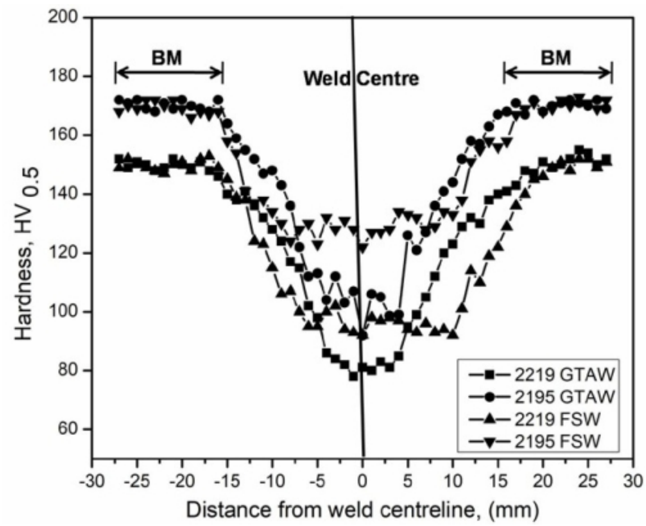

Fig. 7 : Microhardness survey across the 2219 and 2195, GTAW and FSW welds

The hardness variation across the section thickness of the weld region was measured and the changes noticed were marginal. It showed that change in grain size across the section thickness did not affect the hardness significantly.

4.0 CONCLUSIONS

- 2195 alloy base metal showed 15% higher ultimate tensile strength and 31% higher yield strength than 2219.
- Optimized GTAW and FSW welding process parameters for 2195 alloy produced defect free welds.
- As-cast dendritic structure was seen in GTA welds whereas fine recrystallized and equiaxed grains were seen weld nugget zone of FSW welds.
- Weld efficiency of 2195 achieved in with GTAW and FSW processes are 55% and 70% respectively. UTS, 0.2% YS and % elongation of 2195 welds were superior than 2219.
- Fractograph of 2195 welds confirmed that fracture along the dendritic arms in GTAW and weld nugget zone in FSW. Dimple features in both the welds were evident for good ductility.
- Microhardness traverse across the GTAW and FSW welds showed that lowest hardness in the weld region. The hardness trends obtained were analogous to tensile strength and fractography results.
- Overall, FSW process produced high weld strength and good ductility joints without any welding defects.

REFERENCES

[1] Kostrivas A and Lippold JC (1999); Weldability of Li-bearing aluminium alloys, International Materials Reviews, 44 (6), pp. 217 - 236

[2] Eswara Prasad A, Gokhale AA, and Wanhill RJH (2014); Aluminium Lithium alloys, Processing properties and applications, Elsevier.

[3] Mishra RS and Mahoney MW (2007); Friction Stir Welding and Processing, ASM International, Materials Park, Ohio.

[4] Givi B and Kazem M (2014); Advances in friction stir welding and processing, Elsevier, Amsterdam.

[5] Mishra RS and Ma ZY (2005); Friction stir welding and processing, Materials Science and Engineering R 50 pp. 1-78.

[6] Cam G and Mistikoglu S (2014); Recent Developments in Friction Stir Welding of Al - alloys, Journal of Materials Engineering and Performance, 23(6), pp.1936-1953.