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Investigation and Analysis of Metallurgical and Mechanical Properties of AA1100 using FSW

P.Vijayasarathi[1], D.Christopher Selvam[2]

[1]*(Mechanical Department, Anna university Research scholar, Chennai, India)*
[2] *(Asst. Prof., Mechanical Department, Jeppiaar Institute Of Technology, Kunnam, Chennai, India)*

***ABSTRACT*:**

The effect of processing parameters on the mechanical and metallurgical properties of two similar joints of AA1100 produced by friction stir welding was analysed in this investigated. Different FSW samples were produced by varying the rotating spindle speed of the tool as 800 and 1400rpm and by varying the alloy positioned on the advancing side of the tool. In all the experiments the horizontal feed rate is fixed at 75m/min. All the welds were produced perpendicularly to the rolling direction for both the alloys. Micro hardness (HV) and tensile tests performed at room temperature were used to evaluate the mechanical properties of the joints. In order to analyse the micro structural evolution of the material, the weld's cross-sections were observed optically and SEM observations were made of the fracture surfaces.

Keywords –

FSW; Aluminium alloys AA110; Mechanical and metallurgical characterization.

I. INTRODUCTION

Modern aerospace concepts demand reductions in both the weight as well as cost of production of materials. Under such conditions, welding processes have proven most attractive, and programs have been set up to study their potential. Car manufacturers and shipyards are also evaluating new production methods. Increasing operating expenses are driving manufacturers to reduce weight in many manufacturing applications, particularly in aerospace sector. The goal is to reduce the costs associated with manufacturing techniques to result in considerable cost and weight savings by reducing riveted/fastened joints and part count. One way of achieving this goal is by utilising a novel welding technology known as Friction Stir Welding (FSW). Friction stir welding is a solid-state joining process developed and patented by the Welding Institute (TWI) in 1991 by Thomas et al and it is emerged as a welding technique to be used in high strength alloys (2xxx, 6xxx, 7xxx and 8xxx series) for aerospace, automotive and marine applications that were difficult to join with conventional techniques[1,2]. This technique is attractive for joining high strength aluminium alloys since there is far lower heat input during the process compared with conventional welding methods such as Tungsten Inert Gas (TIG) or Metal Inert Gas (MIG). This solid state process leads to low distortion in long welds, excellent mechanical properties in the weld and heat-affected zone, no fumes or spatters, low shrinkage, as well as being energy efficient. Furthermore, other cost reductions are realized in that the process uses a non-consumable welding tool. The process was developed initially for aluminium alloys, but since then FSW was found suitable for joining a large number of materials.

In FSW a non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint. The tool serves two primary functions: (a) heating of work piece, and (b) movement of material to produce the joint. The heating is accomplished by friction between the tool and the work piece and plastic deformation of work piece. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. As a result of this process a joint is produced in 'solid state'. During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine and equiaxed recrystallized grains. The fine microstructure in friction stir welds produces good mechanical properties. Fig. 1 shows a schematic diagram of the FSW process.

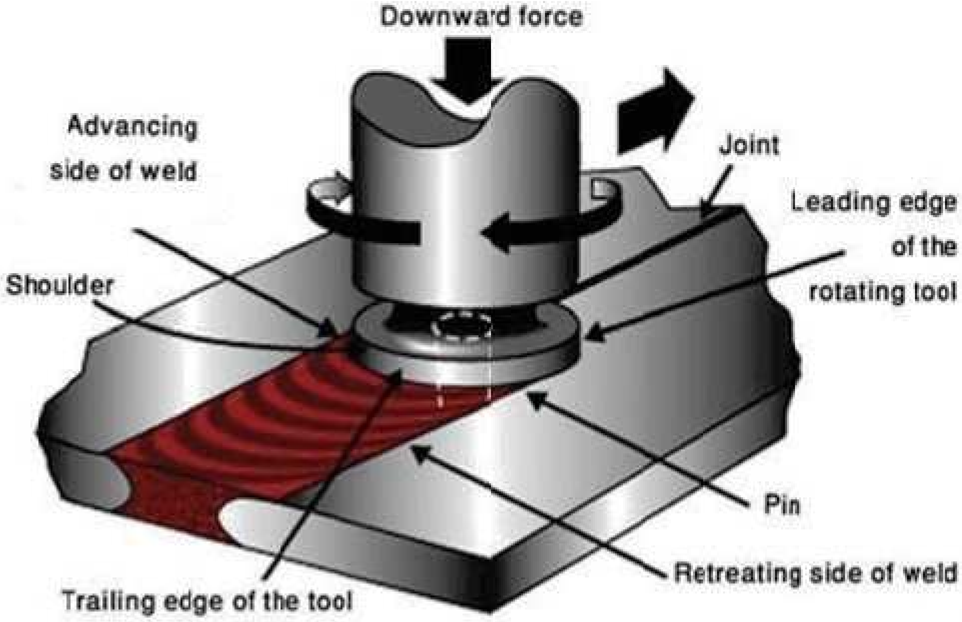

Figure 1*: Schematic diagram of the FSW process.*

Many papers are present in the literature regarding this field. Further to joints of similar alloys, FSW is being studied for welding dissimilar alloys which can be of particular interest in some industrial applications. Some works can be found in the literature [3–7], but data is still scarce on the characterisation of 1100 joint type. Some authors have demonstrated that the microstructure of the weld nugget of strongly different aluminium alloys is mainly fixed at the retreating side of the material [3]. Murr et al. [8] showed the properties of dissimilar casting alloys by FSW. The micro structural evolution of dissimilar welds as a function of processing parameters has been widely studied in [9], showing the behaviour of AA6061–AA2024 materials. Dickerson et al. [10] found that friction-stir-welded butt joints are generally defect free if welding process conditions (welding speed and sheet thickness) are properly tuned within a ‘tolerance box’ for a particular alloy. It is not possible to assume that FSW will be free of flaws, however, because manufacturers may want to run FSW outside the tolerance box in order to increase productivity. The weld zones are more susceptible to corrosion than the parent metal [11-16]. Generally, it has been found that Friction stir (FS) welds of aluminium alloys such as 2219, 2195, 2024, 7075 and 6013 did not exhibit enhanced corrosion of the weld zones. FSW of aluminium alloys exhibit inter granular corrosion mainly located along the nugget’s heat-affected zone (HAZ) and enhanced by the coarsening of the grain boundary precipitates. Coarse precipitates and wide precipitate-free zones promoted by the thermal excursion during the welding are correlated with the intergranular corrosion. The effect of FSW parameters on corrosion behaviour of friction stir welded joints was reported by many workers [14, 16]. The effect of processing parameters such as rotation speed and traverse speed on corrosion behaviour of friction stir processed high strength precipitation harden able AA2219-T87 alloy was investigated by Surekha et al. [16]. However, researchers have nevertheless been strained to study competent study of the mechanical properties in terms of UTS, YS and % elongation, micro hardness test, fractography analysis, and metallurgical properties, and the main causes of developing defects with changing FSW parameters for a two similar aluminium joint of AA1100. Selection of process parameters is an important issue in the FSW process. Present paper, the effect of different welding speeds on the weld characteristics of advancing and retreating side of AA110 and retreating side of AA1100 fabricated by a cylindrical-shouldered tool pin profile is investigated.

2. EXPERIMENTAL PROCEDURE

The experiments were conducted on the aluminium alloy AA110, its chemical composition and mechanical properties are respectively presented in Tabs. 1.The rolled plates of 6.35mm thickness were cut into the required size (100mm×100 mm) by power hacksaw cutting and grinding. Square butt joint configuration was prepared to fabricate FSW joints. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was used to fabricate the joints. In present work cylindrical- shouldered tool pin profile was used for the welds, made of high carbon high chromium steel. The tool dimensions are shown in Fig. 2. The machine used for the production of the joints was vertical machining centre. Different materials positioned on the advancing side of the tool allowed four different welding conditions described in Tab.2.

General Properties of AA1100					
ALLOY	**ULTIMATE TENSILE STRENGTH (PSI)**	**THERMAL EXPANSION COEFFICIENT**	**DENSITY KG/M^3**	**ELASTIC MODULUS**	**MELTING POINT**
AA100	**13,000**	**20.4-25.0×10^{-6}/K**	**2600-2800**	**70-79 GPa**	**660 °C**

Chemical Compositions of AA1100														
ELEMENTS	**Si & Fe**		**Cu**		**Mn**		**Mg**	**Cr**	**Zn**		**Ti**	**others**		**Al**
REQUIRED	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**-**	**-**	**Min**	**Max**	**Max**	**Each**	**Total**	
	Si + Fe	**0.95**	**0.05**	**0.20**	**-**	**0.050**	**-**	**-**	**-**	**0.10**	**-**	**0-0.05**	**0-0.15**	**Balance**
CONTENTS			**0.20**		**0.050**		**-**	**-**	**0.10**		**-**			**Balance**

Mechanical Properties of AA1100						
Tensile Strength (M Pa)		**Yield Strength (M Pa)**		**Elongation %**		**Hardness (HV)**
Min	**Max**	**Min**	**Max**	**Min**	**Max**	
230	**570**	**215**	**505**	**8**	**25**	**90**

Table 1: *Chemical composition and mechanical properties AA1100.*

OVER ALL PROCESS PARAMETERS				
Materials of	**Rotational Speed**	**Vertical Force**	**Vertical Feed**	**Horizontal**

Joints	(rpm)	(Kg)	Rate (m/s)	Feed Rate (mm/min)
AA1100 –AA1100	**800**	**6000**	**0.6**	**75**
	1000	**7000**	**1.2**	**75**
	1200	**8000**	**1.5**	**75**
	1400	**8000**	**1.8**	**75**

Table 2*: Welding conditions employed to join the AA1100 plates.*

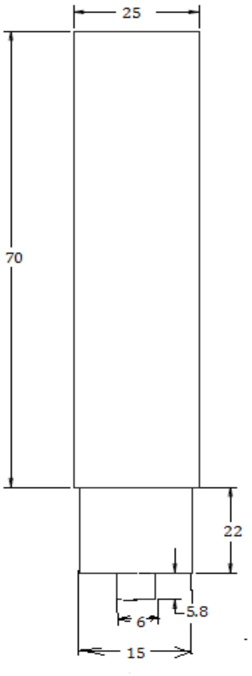

Figure 2*: Geometry of the cylindrical-shouldered tool pin profile used in the present study.*

The design of the tool is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed. The D3-type steel has High carbon High chromium steel tool is selected for welding[8]. The chemical composition of the tool material described in Tab.3.

All welded samples were visually inspected in order to verify the presence of possible macroscopic external defects, such as surface irregularities, excessive flash, and surface-open tunnels. By using Radiographic unit, X-Ray radiographic inspection was carried out on FSW samples. The test is carried out in

Metallurgical microscope- METOSCOPE-1 equipment.

Mechanical properties of the test welds were assessed by means of tensile tests and the ultimate tensile stress (UTS) yield strength (YS) and % elongation were measured in the tensile test. Micro indentation hardness test as per ASTM E-384:2006 has been used to measure the Vickers hardness of FSW joints. The Vickers micro hardness indenter is made of diamond in the form of a square-base pyramid. The test load applied was 1Kg and the dwell time was 15 seconds. The indentations were made at midsection of the thickness of the plates across the joint. The tensile fractured surfaces were analyzed by using scanning electron microscopy (SEM).

Metallographic specimens were cut mechanically from the welds, embedded in resin and mechanically ground and polished using abrasive disks and cloths with water suspension of diamond particles. The chemical etchant was the Keller's reagent. The microstructures were observed on optical microscope.

Thermal and Physical Properties of the Tool material

TOOL	THERMAL EXPANSION COEFFICIENT	DENSITY KG/M^3	ELASTIC MODULUS	MELTING POINT
D3 STEEL	**12×10^{-6}/°C**	**7.7x1000**	**190-210 GPa**	**1421°C**

Chemical Compositions of AA1100

ELEMENTS	C	Mn	Si	Cr	Ni	W	V	P	S	Cu
CONTENTS	**2.00-2.35**	**0.60**	**0.60**	**11.00-13.50**	**0.30**	**1.00**	**1.00**	**0.03**	**0.03**	**0.25**

Table 3: *Thermal Properties, Physical Properties and Chemical composition of D3 steel tool.*

3. RESULT AND DISCUSSION

The mechanical and metallurgical behaviour of two similar FSW AA110 was studied in this research. Transverse tensile properties of FSW joints such as yield strength, tensile strength, and percentage of elongation on transverse tensile specimens are presented in Tab. 4.

Material of FSW Joint	Spindle Speed in RPM	YS (N/mm2)	UTS (N/mm2)	% Elongation
AA1100 (TEST PIECE –I)	800	105.44	110.57	8.00
AA1100 (TEST PIECE –II)	1000	104.89	113.71	16.40
AA1100 (TEST PIECE –III)	1200	87.94	93.37	12.40
AA1100 (TEST PIECE –IV)	1400	91.82	98.62	9.20

Table 4: *Mechanical properties of two similar FSW joints.*

AA1100 (TEST PIECE –I) is welded by 800 rpm tool rotation with vertical force of 6000Kg and the entire tool tip is inserted in to the work piece with vertical feed rate 0.6m/s. At this condition the tool moves entire length of the work piece with horizontal feed rate of 75m/min on the weld path between the weld plates. The onion ring portion of the weld joints looks very rough with excess of materials at the edges of the weld part.

AA1100 (TEST PIECE –II) is welded by 1000 rpm tool rotation with vertical force of 7000Kg and the entire tool tip is inserted in to the work piece with vertical feed rate 1.2m/s. At this condition the tool moves entire length of the work piece with horizontal feed rate of 75m/min on the weld path between the weld plates. The onion ring portion of the weld joints looks little bit improvement on smoothness with less amount of material at the edge of the weld part.

AA1100 (TEST PIECE –III) is welded by 1200 rpm tool rotation with vertical force of 8000Kg and the entire tool tip is inserted in to the work piece with vertical feed rate 1.5 m/s. At this condition the tool moves entire length of the work piece with horizontal feed rate of 75m/min on the weld path between the weld plates. The onion ring portion of the weld joints looks smooth surface with less amount of material at the edges of the weld part.

AA1100 (TEST PIECE –IV) is welded by 1400 rpm tool rotation with vertical force of 8000Kg and the entire tool tip is inserted in to the work piece with vertical feed rate 1.8 m/s. At this condition the tool moves entire length of the work piece with horizontal feed rate of 75m/min on the weld path between the weld plates. The onion ring portion of the weld joints looks very fine smooth surface with less amount of material at the edges of the weld part. Fig.3. shows the Effect of welding speed on mechanical properties for two similar alloys AA1100

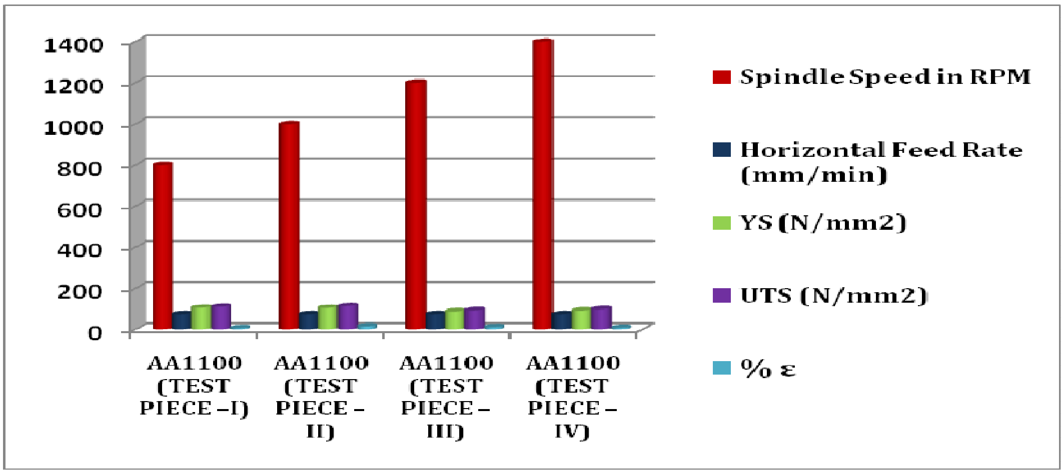

Figure 3 : *Effect of welding speed on mechanical properties for two similar alloys AA1100-AA1100.*

3.1. Microstructure and Hardness Test:

This test is carried out in Metallurgical microscope-METOSCOPE-1 equipment. The microstructure at the FSW joints shows fine Al-Fe-Si and MgSi particles and at the base shows elongated Al-Fe-Si and MgSi particles in a matrix of aluminum solid solution. The fig. 4.shows the microstructure of the FSW joints. The hardness test is carried out in Vickers hardness test machine at FSW joints in weld region. Heat affected zone (HAZ) and base metal with 1Kg load. The various values are obtained from the FSW joints. Fig.5. shows the Effect of welding speed on micro hardness for similar alloys AA1100

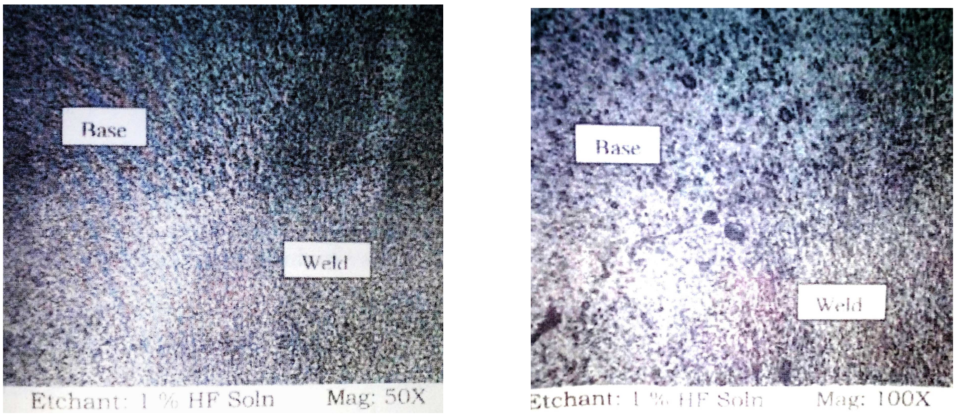

Figure 4: *SEM images of FSW joints of AA1100*

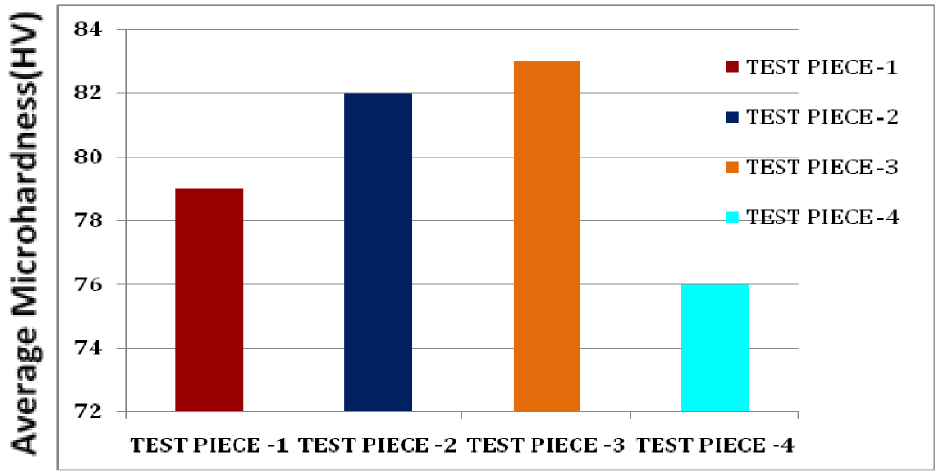

Figure 5 :*Effect of welding speed on micro hardness for similar alloys AA1100*

3.2. Macro Examination Test

This test is carried out in Stereomicroscope in 10X zoom level observation, in this test the samples was macro etched and examined visually reveals complete fusion between weld and base metal. So, its concluded there is no presence of any weld defects like lack of fusion, lack of penetration or excess penetration, porosity, inclusions, cracking, undercut, lamellar tearing, etc. The macro structure is shown in following fig.6.

Figure 6:*Macro structure of FSW joints*

4. CONCLUSION

The mechanical and metallurgical behaviour of two similar FSW AA1100 was studied in this paper. The joints were produced with same alloy positioned on the advancing side of the tool. The joints were realized by changing with a rotation speed from 800 to 1600 rpm and the horizontal feed rate is fixed at 75 mm/min. The downward force was observed to be constant as the horizontal feed rate for all the produced joints increases. The tensile strength of the similar joint is lower than that of the parent metal. The similar joints exhibited good mechanical properties and Micro structural changes induced by the friction stir welding process were clearly identified in this study. A softened region has clearly occurred in the friction stir welded joints, due to dissolution of strengthening precipitates.

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