Ashutosh Pandey al. International Journal of Recent Research Aspects ISSN: 2349-7688, Vol. 2,Issue 2, June 2015, pp. 219-227

Behavioral Characterisation of Friction Stir Welded Aluminium Joints

Ashutosh Pandey[1], Mohd. Abbas[2], Manish Giri[3]

[1,2,3]Al-Falah School of Engineering and Technology, Dhauj, Faridabad , Haryana

ABSTRACT : Friction stir welding (FSW) is a recently developed innovative welding technique. FSW is successful in joining materials, which were considered impossible to weld by conventional methods. Its capability to produce welds with excellent mechanical and metallurgical properties gained its importance in industrial applications. However, FSW is applied in welding of complex profiles and needs heavy duty equipments. FSW has made welding more flexible. The base material used was 6mm thick commercially pure aluminium cold rolled plates. Welding is a fabrication process used to join materials, usually metals or thermoplastics, together. During welding, the work pieces to be joined are melted at the joining interface and usually a filler material is added to form a weld pool of molten material that solidifies to become a strong joint. In contrast, Soldering and Brazing do not involve melting the work piece but rather a lower melting point material is melted between the workpieces to bond them together. The welds were made in butt joint configuration at three different tool rotational speeds namely 900 rpm, 1120 rpm and 1400 rpm under a constant tool feed rate of 25mm/s. Macrostructural, microstructural and microhardness studies have been carried out. Tensile samples were made from the welded joints and tested to find out the joint strength. Maximum joint strength obtained was 118.66 MPa at 1120 rpm with a joint efficiency of 71%. Finally the results obtained from FSW have been concluded

Keywords: FSW, shoulder tool, aluminium, mechanical testing

I. INTRODUCTION

In our day to day life we make use of welded products directly or indirectly. American Welding Society defines welding as 'localized coalescence of metals or non metals produced by heating the materials to a welding temperature, with or without the application of pressure or by the application of pressure alone and with or without the use of filler metal'. Welding processes can be broadly divided into fusion welding process and solid state welding process.

Solid state welding: Solid state processes produce coalescence of the faying surfaces at temperatures below the melting point of the base metal being joined, without the addition filler metal. Some of the major advantages of the solid state processes are mentioned below:

- It is capable of joining dissimilar materials with much ease
- Filler material not needed
- Shielding gases not required
- Less influence on metallurgical properties of the welded material.
- Environment friendly

Friction stir welding (fsw) : Friction stir welding (FSW) is an innovative welding technique, invented by Wayne Thomas of The Welding Institute (TWI), Cambridge, UK and patented in 1991. FSW has been successfully used to weld similar and dissimilar cast and wrought aluminum alloys, steels, as well as titanium, copper and magnesium alloys, dissimilar metal group alloys and metal matrix composites. The technique can be used to produce butt, corner, lap, T, spot and fillet joints as well as to weld hollow objects, such as tanks and tube / pipe, and parts with 3-dimensional contours. FSW technique utilizes a non-consumable rotating tool of harder material than the base material, to generate frictional heat and plastic deformation at the welding location.

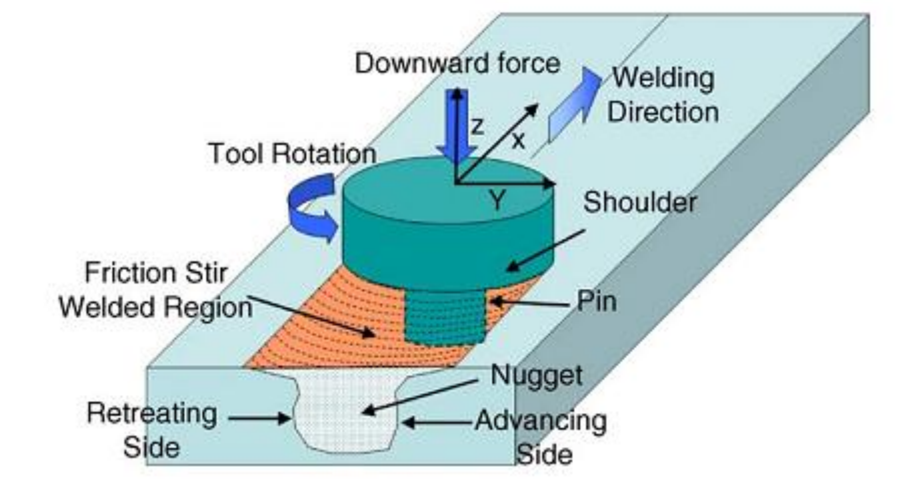


Figure: Schematic diagram of FSW

Today FSW technique is applied in many areas including critical applications in defence and aerospace. Some of the areas where FSW is used are listed below

- Manufacturing of rocket-fuel tanks airframes, fuel tanks, and thin alloy skins in the aerospace.
- The Eclipse 500 business class jet was one of the civil aircraft produced by FSW components
- Seams in the fuel tanks of a Boeing Delta II Rocket launched in August 1999 had friction stir welded joints.
- Sheet bodywork and engine support frames for the automotive industry.
- Railway wagon and coachwork, and bulk carrier tanks for the transportation industry.
- Hulls, decks, and internal structures for high speed ferries and LPG storage vessels for the shipbuilding industry
- The panels made by FSW of Marine Aluminium were used in a vessel manufactured by Fjellstrand AS in 1996.

Base material properties-

ALUMINIUM: Aluminum, an abundant metal on earth, became an economic competitor in engineering applications as recently as the end of the 19th century.

Table 1:Properties of Aluminium

Crystal Structure	Face centric cubic
Melting point	660.4^{0}C
Density	2.6989 g/cc
Thermal conductivity	247 W/m. K
Tensile strength	165 Mpa

Process parameters-

TOOL GEOMETRY : An FSW tool consists of a shoulder and a pin as shown schematically in Fig.

The tool has two primary functions: (a) localized heating, and (b) material flow. In the initial stage of tool plunge, the heating results primarily from friction between pin and workpiece. Some additional heating results from deformation of material. The tool is plunged till the shoulder touches the workpiece. The friction between the shoulder and workpiece results in the biggest component of heating. From the heating aspect, the relative size of pin and shoulder is important, and the other design features are not critical. The shoulder also provides confinement for the heated volume of material. The second function of the tool is to 'stir' and 'move' the material. The uniformity of microstructure and properties as well as process loads are governed by the tool design.

Welding Parameters: For FSW, two parameters are very important: tool rotation rate (v, rpm) in clockwise or counterclockwise direction and tool traverse speed (n, mm/min) along the line of joint. The rotation of tool results in stirring and mixing of material around the rotating pin and the translation of tool moves the stirred material from the front to the back of the pin and finishes welding process. Higher tool rotation rates generate higher temperature because of higher friction heating and result in more intense stirring and mixing of material as will be discussed later. However, it should be noted that frictional coupling of tool surface with work piece is going to govern the heating. So, a monotonic increase in heating with increasing tool rotation rate is not expected as the coefficient of friction at interface will change with increasing tool rotation rate. In addition to the tool rotation rate and traverse speed, another important process parameter is the angle of spindle or tool tilt with respect to the work piece surface. A suitable tilt of the spindle towards trailing direction ensures that the shoulder of the tool holds the stirred material by threaded pin and move material efficiently from the front to the back of the pin. Further, the insertion depth of pin into the work pieces (also called target depth) is important for producing sound **welds with smooth tool shoulders**

Joint Design:

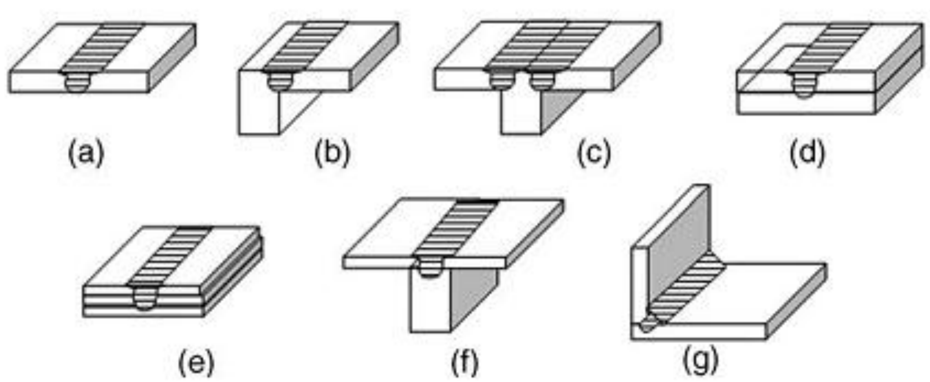


Figure 1.1: Joint configurations for friction stir welding: (a) square butt, (b) edge butt, (c) T butt joint, (d) lap joint, (e) multiple lap joint, (f) T lap joint, and (g) fillet joint.

II. OBJECTIVE

The major objectives of present work are listed below

- make FSW joints by a shoulder tool on aluminium alloy
- haracterisation and mechanical testing of the joints made.

III. LITERATURE REVIEW

Friction stir welding (FSW) is a revolutionary welding technique, invented by Wayne Thomas of The Welding Institute (TWI), Cambridge, UK and patented in 1991. In the present work an attempt has been made to join aluminium plates by FSW technique and the results have been compared with conventional FSW.

Tozak et al. (2010) newly developed tool for friction stir spot welding (FSSW) has been proposed, which has no probe, but a scroll groove on its shoulder surface (scroll tool). By use of this tool, FSSW has been performed on aluminium alloy 6061-T4 sheets and the potential of the tool was discussed in terms of weld structure and static strength of welds. The experimental observations showed that the scroll tool had comparable or superior performance to a conventional probe tool.

S. Rajakumar et al. (2011) observed that AA6061 aluminium alloy has gathered wide acceptance in the fabrication of light weight structures requiring high strength-to-weight ratio and good corrosion resistance.

Bhatt (2013) In this research we observed that Friction stir welding (FSW) of AA6061-T6 aluminium alloy has been attempted to overcome limitations of fusion welding of the same. The FSW tool, by not being consumed, produces a joint with predominant advantages of high joint strength, lower distortion and absence of metallurgical defects.

IV. EXPERIMENT DETAILS OF FSW

Welding was carried out in an in-house developed, modified vertical milling machine. The machine consists of a vertical tool holder, spindle, table and a supporting structure as shown in Fig.. The tool was fixed on the tool holder. The plates to be welded were clamped on a specially designed clamping block to facilitate the movement of shoulder tool. The machine has the provision to change the tool rotational speed.

FSW machine

Parent material and tool

Commercially pure aluminium (CP Al) cold rolled plates of 6mm thickness were used as the base material at different stages of the present study. The plates were made into required size (100mm x 50mm x 6mm) and edges were made flat. Plates were polished to remove oxide layer. After polishing, plates were thoroughly cleaned with acetone to remove all the debris like grease, dirt etc

Table:(a) Chemical composition of CP Al base material

Element	Cu	Si	Fe	Mn	Mg	Zn	Al
Wt%	0.05	0.250	0.35	0.03	0.03	0.05	balance

Material used for welding tool was EN 31 series high carbon steel.

Table 3.1:(b) Chemical composition of EN 31 tool material

Element	C	Mn	Si	Cr	Ni	Mo	V	W	Fe
Wt%	0.87	0.36	0.30	3.71	0.31	4.31	0.95	2.05	balance

Shoulder diameter	20mm
Pin diameter	6.66mm
Pin length	5.7mm

:

Dimensions of the tool used in conventional FSW

PROCESS PARAMETER

In the present study, investigations were done by varying tool rotation speed only. All the other parameters were kept constant. Process parameters used in this study are shown in table

Table:Process parameters

Tool rotation speed	**900rpm** **1120rpm** **1400rpm**
Feed rate	**25mm/min.**

V. EXPERIMENT DESIGN

The present study was carried out in two stages

- ✓ **Stage 1-** Friction stir welding of CP Al plates by shoulder tool
- ✓ **Stage 2-** Mechanical and metallurgical properties of the joints made in above stage were examined
- ✓ **Stage 3-** Results

VI. ANALYSIS OF WELDED SAMPLES

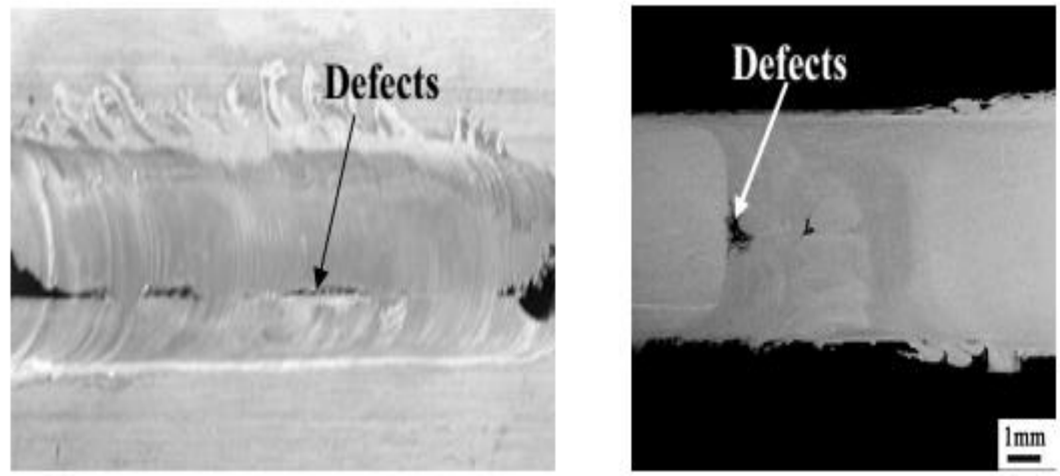
Microstructural and macrostructural studies-

After completion of welding, the welded joints were sectioned in the transverse direction, samples were prepared and polished with emery sheet of different grades; further polishing had been done using alumina polishing and diamond polishing with 1μm diamond paste. Suitable etchants were used to etch the specimen. Microstructures and macrostructures were taken using optical microscope.

VII. RESULTS AND DISCUSSIONS

Trial set 1

To fix the shoulder tool dimensions



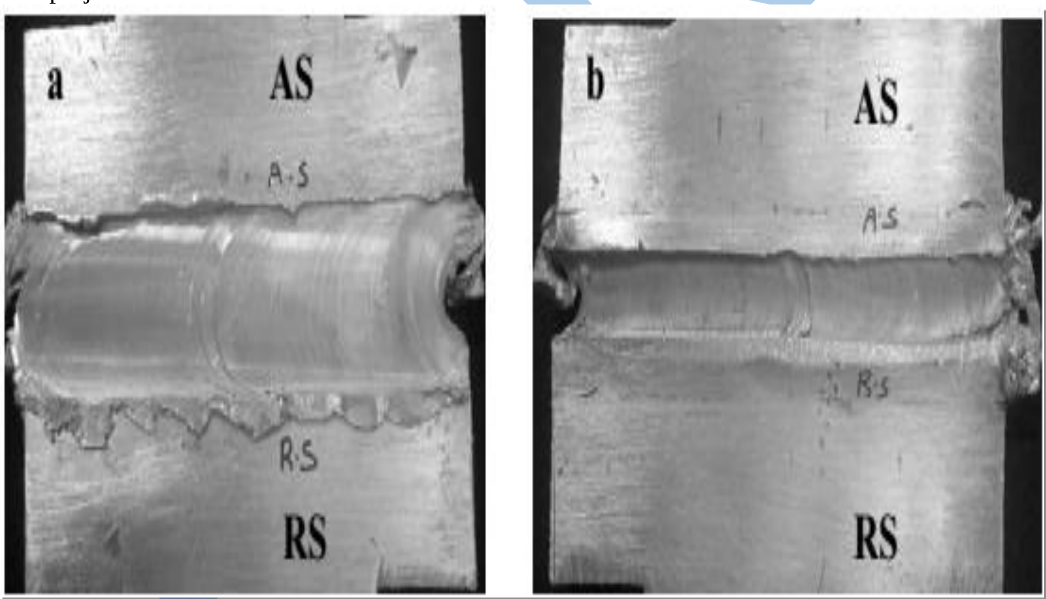
Defects in FSW

Trial set 2

After fixing the process parameters and tool dimensions, stage-1 of the project was executed

STAGE-1

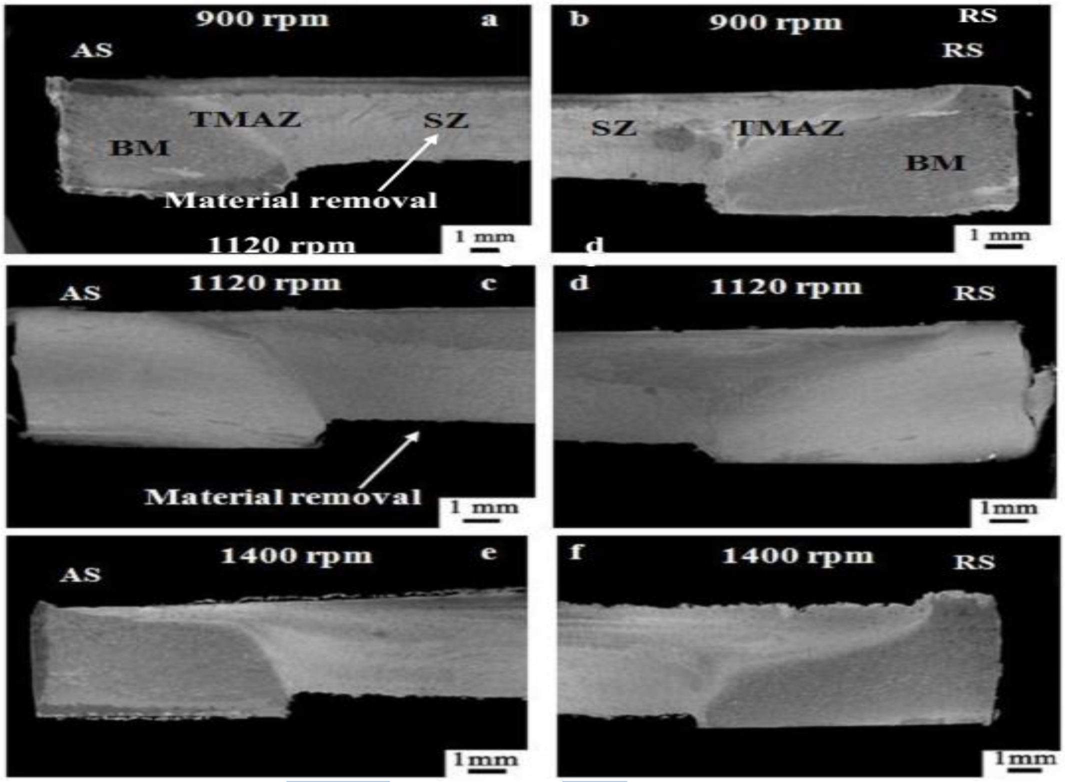
Characterization and mechanical testing of the joints have been carried out.



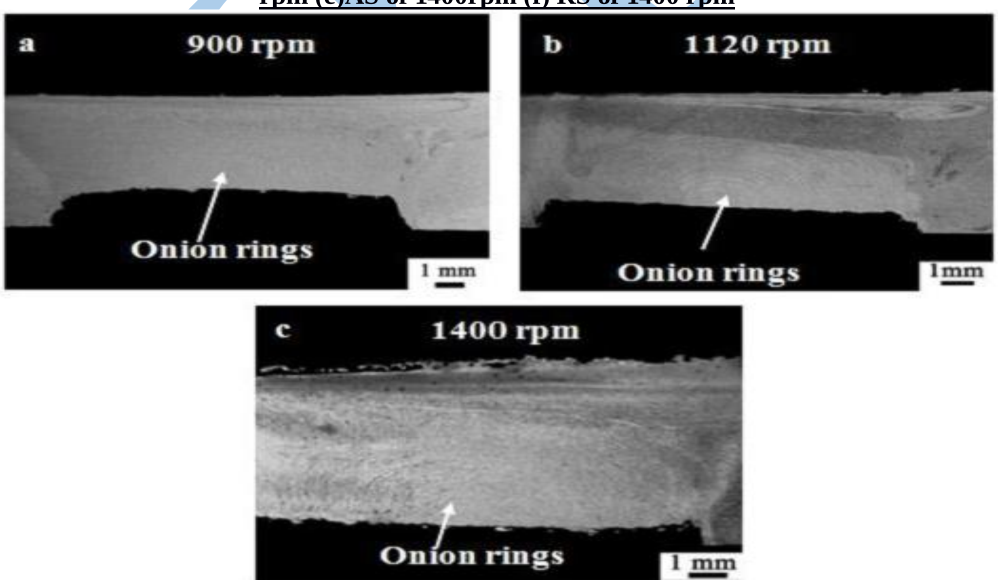
Welded sample by FSW

Macrostructure

Samples were prepared according to standard metallographic procedures and etched with Poultron reagent (30ml HCl, 40ml HNO3, 2.5 ml HF, 12 g CrO3 and 52.5 ml H2O). Fig. 4.3 shows the macrostructure of the welds made at 900 rpm, 1120 rpm and 1400 rpm. All the macrostructures show defect free weld joints. Material loss due to the tool gap used is evident in all samples. Onion ring like structures were observed in SZ of all the samples (shown in Fig.4.4). This shows the perfect material flow during welding and compactness of the welds.



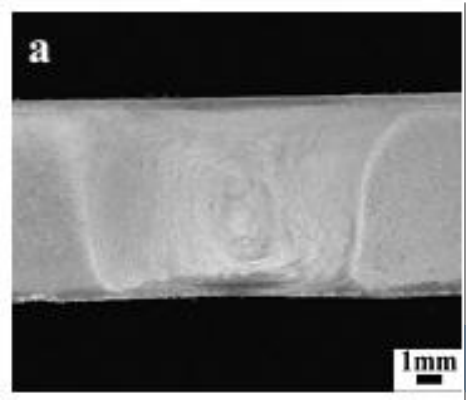
<u>**Macrostructures of the welds by FSW (a)AS of 900 rpm (b)RS of 900 rpm (c)AS of 1120 rpm(d)RS of 1120 rpm (e)AS of 1400rpm (f) RS of 1400 rpm**</u>



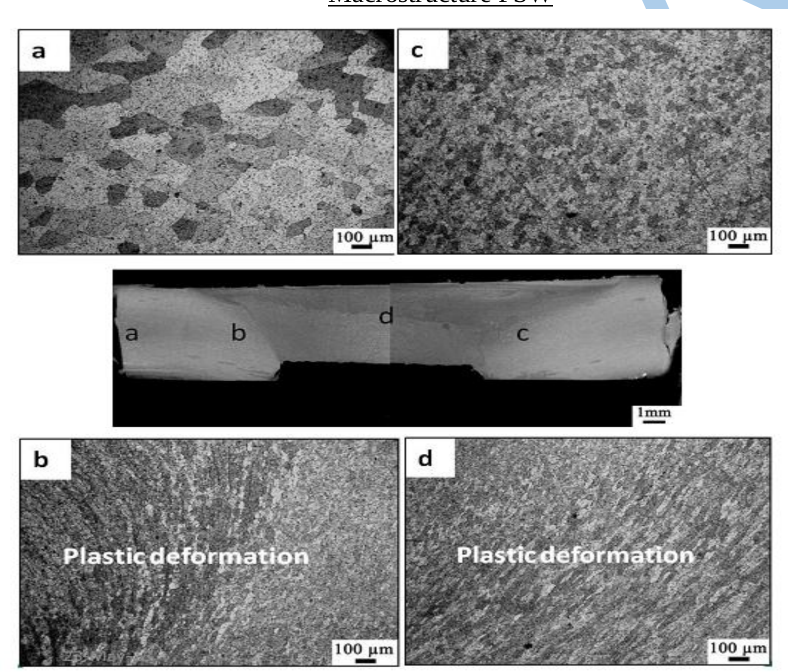
<u>Onion rings at the weld zone (a)900 rpm (b)1120 rpm (c)1400 rpm</u>

Microstructure

Samples were prepared according to standard metallographic procedures and etched with Poultron reagent (30ml HCl, 40ml HNO3, 2.5 ml HF, 12 g CrO3 and 52.5 ml H2O)..Different zones were observed in the weld cross section after etching. In all the samples fine grains were obtained in the SZ when compared to TMAZ and BM. TMAZ grains were large and elongated due to the combine effect of frictional heat and mechanical stirring. Different zones are shown in Fig.4.5. One of the unique feature observed in the microstructure was three modes of metal transfer.



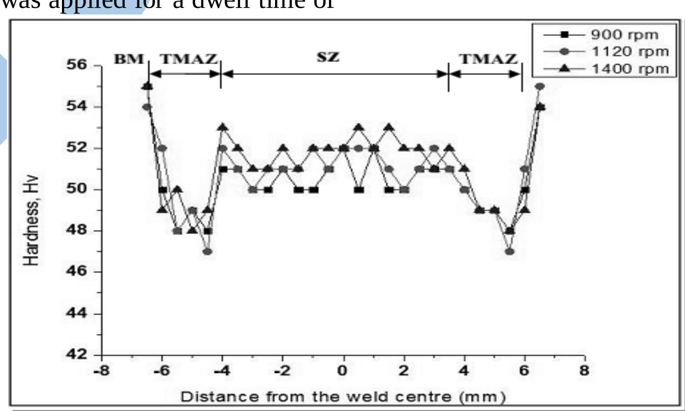
Macrostructure FSW



Microstructures at different regions-FSW

Microhardness

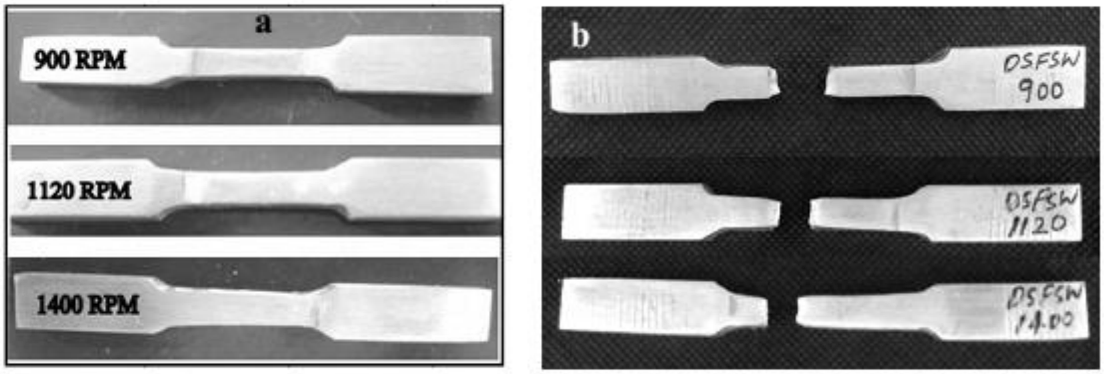
Microhardness readings were taken in a Vickers microhardness tester along the mid thickness of the welded plate. 0.5 kg load was applied for a dwell time of 20 secs and readings were taken at a span of 0.5mm. Hardness distribution of the samples welded at three tool rotation speeds are shown in Fig.



Microhardness distribution- FSW

Mechanical Testing

Tensile samples were prepared from the welded joints and were tested according to the standard testing procedures.



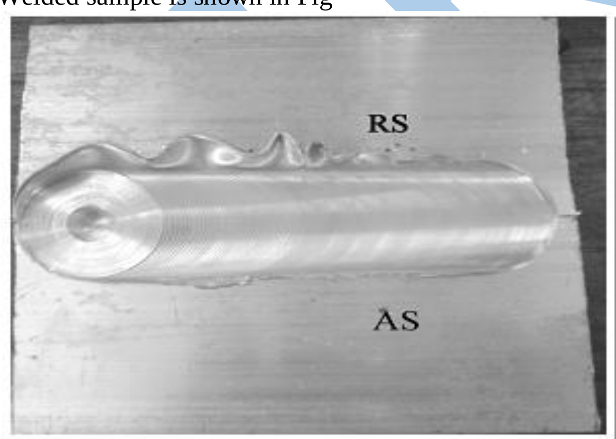
Tensile samples-FSW (a) before testing (b) after testing

Mechanical properties

Tool RPM	UTS (MPa)	Joint efficiency	Failure location
900 RPM	118.2	70%	SZ
1120 RPM	118.66	71.2%	SZ
1400 RPM	113.57	65.9%	SZ

FINAL STAGE

After successful welding by FSW technique in Stage 1 and Stage 2, study of FSW has been carried out. All the tool dimensions were same except the pin length. Welded sample is shown in Fig



Welded sample- FSW

Morphology of welded joint

In FSW, there will be a hole left out after tool withdrawal. . This may result in better corrosion resistance or may increase the strength of the joint

Weld strength

The strength has been shown in table 4.2. FSW joints showed almost similar strength in all the tool rotation speeds. It is clear that in the FSW welds at 900 rpm and 23.5% more strength at 1120 rpm. Strength of FSW joints at 1120 and 1400 rpm. All the FSW joints failed in the SZ.

1 **FSW Tensile test results**

Tool RPM	Strenght (MPa)	Failure Location
900	**118.2**	**SZ**
1120	**118.66**	**SZ**
1400	**113.57**	**SZ**

VIII. CONCLUSIONS AND FUTURE SCOPE

Friction stir welding has been successfully carried out. Important conclusions from the present work are listed below:

- Commercially pure aluminium plates of 6mm thickness were successfully welded by FSW technique at different tool rotation speeds and resulted in defect free welds.
- Maximum joint strength obtained was 118.66 MPa at 1120 rpm with a joint efficiency of 71%.
- Two modes of metal transfer have been observed in the welds.
- Initial FSW technique employed caused material loss while welding and thus resulted in stress concentration in the joints.
- SZ hardness of refilled region was higher than the SZ of base material region.

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