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Experimental Evaluation of Mechanical Properties and Microstructure of Friction Stir Welded 5083 Aluminium Alloy

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Abstract:
Friction stir welding (FSW) process is a solid state welding method developed by The Welding Institute (TWI) and now it is increasingly used in Aluminium welding. A study has been made of the FSW of 4mm thick Aluminium alloy 5083 plates. By considering the two different tool rotation speeds and by changing the transverse feeds, the mechanical properties vary. It is seen that higher mechanical properties are acquired at a revolution speed of 1400 rpm and welding rate of 40mm/min. It is also observed that the fine microstructure obtained at the above mentioned condition. The mechanical properties were watched and related with the microstructure. The tool-rotation speed varied from 710r/min to 1400r/min and the Welding speed is constant at 40 mm/min, and there is no tool tilt angle used. In this review the process parameters, microstructural evolution, and effect of friction stir welding on the properties of weld specific to aluminum alloys have been discussed.

Keywords: Friction stir welding, tool, welding parameters, Mechanical Properties, Microstructure

1. INTRODUCTION

The 5083 aluminum combination is shown great consumption protection from seawater, better mechanical properties. It has great formability, machinability and weldability. The 5083 aluminum combination is utilized for giving of welded parts to shipbuilding and railroad vehicles. It has the highest strength of the non-heat treatable alloys. [1-2] It is not recommended for use in temperatures in excess of 65^0 c to a corrosive environment. [3]Many studies were made on the weld ability of 5083 aluminium alloy. [4-6]Aluminium alloys are friction-stir processed (FSP) then the properties of super plastic are obtained, as a consequence of grain refinement. [7]Friction stir processing (FSP) is used to transform a heterogeneous microstructure to a more homogeneous, refined microstructure before not getting its melting temperature. In this study the investigation was done on weld ability of 5083 aluminium alloy using the technique of friction stir welding (FSW). The weld parameters like tool-rotation speed, the welding speed was measured in this study. The FSW is employed a tool-rotation speed from 710 r/min to 900 r/min.

2. LITERATURE REVIEW

The welding of aluminium and its alloys has always represented a great challenge for researchers and technologists. Friction stir welding (FSW) is a new welding process that has produced low cost and high quality joints of aluminium alloys. For carrying out research work in any area, the first and an important phase is to review the available literature for the selected topic and the research problem can be formulated with clear objectives.

Hirata et al., (2007) [5]developed the association between the microstructure of stir zone and the mechanical properties of FS-welded 5083 aluminium alloy. The microstructures of the stir zones consisted of fine equiaxed grains at various FSW circumstances. The grain size of the stir zone decreased with the decrease in friction heat flow during FSW. The results shown that the micro structure and mechanical properties of the FS-welded 5083 Al alloy joints were improved by the refinement of grain size of the stir zone.

Lombard et al., (2008) [6] in this research work present a systematic approach to optimizing FSW process parameters (tool rotational speed and feed rate). Eleven experiments were conducted by varying the tool rotational speed and welding speed. The tensile strength of the joint was increased from 289 to 313 MPa by varying the tool rotational speed from 400 rpm to 200 rpm at the constant welding speed of 85 mm/min. The tensile strength of the joint increased from 254 MPa to 315 MPa by changeable the tool rotational speed from 635 rpm to 254 rpm at the constant welding speed 135 mm/min. The work indicates that the tool rotational speed is the key parameter governing the tensile strength.

Min-Su Han et.al., [7] in this survey mechanical characteristic for friction stir welding (FSW) of 5083-O Al alloy were evaluated. The results show that in FSW at 800 r/min and 124 mm/min, a weld defect is observed at the start point. However, the button shape at the end point is good and the stir zone has a soft appearance. At 267 mm/min, a void occurs at the button. A slight weld defect and rough stir zone are seen both at the start and end points at 342 mm/min. Moreover, at the bottom, a tunnel-type void is observed from an early stage to the end point, and at 1800 r/min, a weld defect can be found from an early stage to the end point. These defects are rough with imperfect joining due to excessive rotation speed and high physical force. Weld fractures relative to rotational and travel speeds are observed at the stir zone. The optimum FSW conditions are a welding speed of 124 mm/min and a rotational speed of 800r/min.

Damjan Klobcar et.al., **[8]** A study was made of the weldability of 4-mm-thick aluminium-alloy 5083 plates using friction-stir welding. A plan of experiments was prepared based on the abilities of a universal milling machine, where the tool-rotation speed varied from 200 r/min to 1250 r/min, the welding speed from 71 mm/min to 450 mm/min and the tool tilt angle was held constant at 2°. The factors feed per revolution (FPR) and revolutions per feed (RPF) were introduced to get a better insight into the friction-stirring process. Samples for microstructure analyses, Vickers micro-hardness measurements and special miniature tensile-testing samples were prepared. The microstructure was prepared for observation on a light microscope under a polarized light source. A set of optimal welding parameters was determined at a FPR of 0.35 mm/r, at which quality welds, can be made with a minimal increase in the weld hardness and an up to 15 % drop in the tensile strength. Keywords: friction-stir welding, AA 5083, welding parameters, mechanical properties, welding defects.

E. Fereiduni *et al*. **[9]** Used Al-5083 and steel alloy St-12 alloy sheets with the thicknesses of 3 and 1 mm as a material for friction stir welding. Temperature variation at the joint interface was calculated. Rotational speeds of 900 and 1100 rpm were used with the dwell times of 5, 7, 10, 12 and 15 seconds to weld material. Then tensile and shear test are conceded out on three specimens for each processing condition and the average values were recorded. They found that when the dwell time increases joint strength increases up to certain limit and then start declining.

3. EXPERIMENTAL PROCEDURE

3.1. EQUIPMENT DETAILS

The main material used in the experiments was 5083-O (Si 0.122%, Fe 0.250%, Cu 0.024%, Mg 4.528%, Cr0.076%, Zn 0.023%, Ti 0.011%, Al Bal. mass fraction) Al alloy, the most commonly used material for vessel construction among the 5000-series of Al alloys. The experimental study includes the butt joining of 4 mm AA 5083 plates. The welding process is carried out on a vertical milling machine (Make HMT FM-2, 10hp, 3000rpm) as shown in fig 1. Tool will be held in tool arbor. Special welding jigs and fixtures are designed to hold two plates of 150 mm X 75 mm X 4 mm thickness as shown in fig 2. The process parameters are tool rotational speed (RPM), welding speed (mm/min), and tool geometry and diameter of the tool shoulder to the diameter of the tool pin (Ds/Dp). These combinations are chosen based on the literature survey and the capability of the milling machine used for the experimental study.

Figure.1. Schematic Diagram of Vertical Milling Machine

3.2. WELDING PROCESS

FSW is a solid state joining process conceded out on a vertical milling machine. The plates to be welded are at first machined to the necessary dimensions and the process operations. A clamping system must keep the work-pieces rigidly fixed using fixtures onto a backing bar to stop the abutting joint faces as shown in the figure 3. Prior to welding initially a hole is made using a drill bit that is set in the tool holder then the drill bit in the tool holder is replaced with the weld tool. Then the shouldered pin is rotated at steady speed and plunged into the joint line between the two metal sheets butted together.

3.3 WORK MATERIAL DIMENSIONS

The work material is aluminium 5083 plate having 150 mm X 75 mm X 4 mm thickness dimensions.

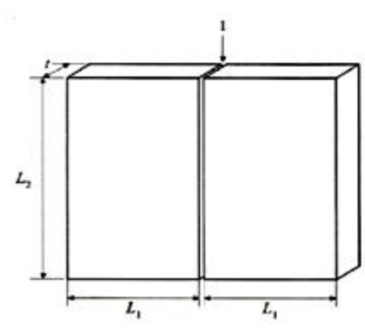

Figure .2. Work material dimensions

Figure.3. Experimental FSW

3.4 FSW PROCESS PARAMETERS

Tool rotation speed (rpm)	:	710, 900, 1120, 1400
Welding speed (mm/min)	:	40
Pin length (mm)	:	3.7
Tool shoulder diameter (D),		
Tool pin diameter (d) (mm)	:	24, 6
D/d ratio of tool	:	4
Tool pin geometry	:	tapered conical profile
Tool material	:	High speed steel

3.5 TOOL GEOMETRY

Non consumable tool prepared of HSS tool steel (Typical chemical composition is shown in the Table 2) is used to manufacture joints, and diameters of shoulder 24, and pin used were 6 mm and the length of the pin 3.7 mm (depend on the plate thickness). The tools used for the nearby study are tapered conical pin profiles with shoulder as shown in Figure 4

3.6 CHEMICAL COMPOSITION OF WORK MATERIAL AND TOOL

Chemical Composition of 5083 Aluminium alloy

Table.1. Chemical Composition of 5083

Chemical Element	% Present
Al	92-94
Fe	0.4
Cu	0.1
Mg	4.0-4.9
Mn	0.4-1.0
Si	0.4
Zn	0.25
Ti	0.15
Cr	0.05-0.25

Chemical composition of HSS tool

Table .2. Chemical Composition of tool

Element	% Weight
Carbon	0.37 – 0.42
Manganese	0.20 – 0.50
Phosphorus	0 - 0.025
Sulphur	0 – 0.005
Silicon	0.80 – 1.20
Chromium	5.00 – 5.50
Vanadium	0.80 – 1.20

3.7 Abbreviations and Acronyms

TWI - The Welding Institute
FSW - Friction Stir Welding
Ds - Diameter of tool shoulder
Dp - Diameter of tool pin
FPR - feed per revolution
SP - friction stir processing
RPF - revolution per feed

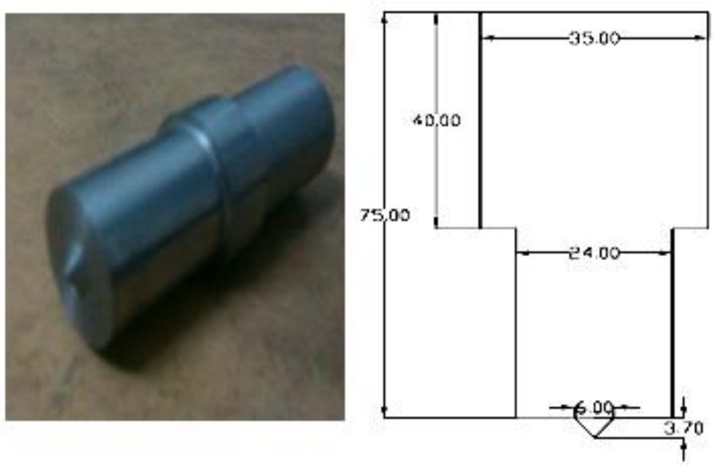

Figure.4. FSW tool geometry

4. RESULTS AND DISCUSSIONS

Table .3. Mechanical Properties at tool rotational speeds 710 rpm, 900rpm, 1120rpm & 1400rpm with welding speed of 40 mm/min:

Condition FSW (rpm/mm)	YS (M Pa)	TS (M Pa)	Elongation (%)	Rockwell's Hardness Value	Impact strength(J)
710/40	120.5	135.5	3.64	80.4	15
900/40	93.5	184.1	5.54	96	16
1120/40	110.8	180.5	9.4	94.3	20
1400/40	101.3	211	17.5	94.1	28

4.1 Mechanical Properties:
From the outcomes the tensile strength increases as the tool rotation increases. At 710r/min the strength was 120.5 M Pa and at 900r/min the strength shows slight improvement i.e., 184.1MPa. And the % elongation is 3.64 at lower rotation speeds i.e., 710rpm. The highest tensile strength and elongation ratios were drastically upper than those at other travel speeds. Two probable reasons exist. The first involves insufficient heat participation with material flow during FSW and a fast cooling rate. In general, the heat input at a low rotational speed of probe is small and the cooling rate of the weld is rapid with increasing travel speed. The optimum tool rotational speed is 1400 rpm as the material flows plastically and intermolecular arrangement occurs at this condition.

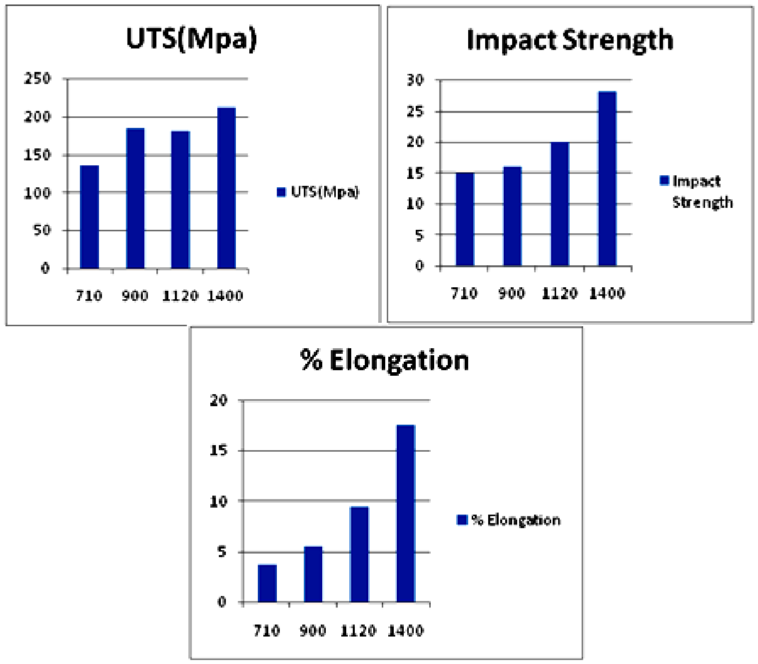

Figure. 5.Tool Rotational speed Vs UTS, Impact Strength and % Elongation

4.2 Microstructure Observations:
The microstructure of stirred zone (SZ) consists of equiaxed grains in much smaller size compared to the large elongated grains of base metal (BM). Grain refinement in weld metal has been achieved due to frictional heating and plastic flow. Most of the previous works on AA aluminum alloy friction stir welded showed that SZ zone had a dynamically recrystallized fine grain structure with high fraction of high angle grain boundaries. Grain size decreases with increasing rotation speed. In addition, increasing rotation speed resulted in finer and more homogenous distributions of particles in SZ. The equi-axed grain size obtained at 1120rpm and 1400rpm as compared with 710 and 900rpm. From the Microstructure observation it is concluded that at 1400 rpm, the grains are recrystalined and homogeneous mixture of grains obtained due to sufficient heat input.

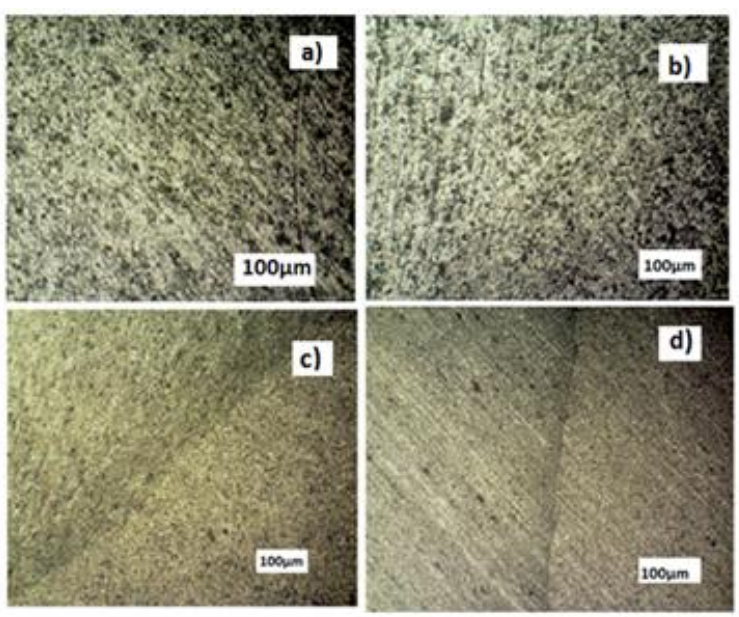

Figure.6. microstructure of FSW welds obtained at 710rpm, 900rpm, 1120rpm & 1400rpm at welding speeds of 40mm/min

5. CONCLUSIONS

Welding of AA5083 in FSW process successfully obtained for different welding speeds, rotation speeds and the tool profile. Based on the analyzed results the following can be concluded.

1. It is observed that at rotation speed of 1400 rpm, & 40 mm/min welding speed with conical profile resulted in good mechanical properties.
2. It is accomplished that, at 1400 rpm, the mechanical properties are better than at 900 rpm, 1120 rpm, this is due to sufficient heat is obtained at this condition. Hence weld with conditions 1400 rpm & 80 mm/min gives the best results among all these welds.
3. It is to be concluded that for different welds of microstructure, 1400rpm with 40mm/min and 900rpm with 40mm/min the grain size was very small. More grain refinement was there in this condition due to the cold deformation effect. [9]
4. The most favorable condition is tool rotational speed 1400rpm and welding speed at 40mm/min, and at this circumstance the mechanical properties and microstructure results correlated.

6. FUTURE SCOPE:

The temperature at the welding zone is high and dissipated to surrounding atmosphere. For that temperature distribution in friction stir welding of aluminium 5083 alloy to be done in this area of work by varying tool geometry and process parameters.

7. ACKNOWLEDGEMENTS

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