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Study of Mechanical Properties Change During Friction Stir Spot Welding of Aluminium Alloys

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***Abstract* - The Friction Stir Welding process is now 20 years old and the interest in it and its potential continues to increase dramatically. FSW can be applied to a multitude of products with varying material types and thicknesses. However, a continuous weld is not always required to meet the product performance requirements. Thus, one can consider some form of intermittent weld, such as Friction Stir Spot Welding. Friction Stir Spot Welding (FSSW) can be considered for many of the applications presently performed with traditional resistance spot welding (RSW), *the basic concept of FSSW* is remarkably simple. 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 the tool serves two primary functions: (a) heating of work-piece, and (b) movement of material around pin 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 axial load. As a result of this process a joint is produced in 'solid state'. From using this method to perform the Welding tests were performed using two welding parameters and the welds were sectioned and evaluated using optical microscopy. Mechanical testing of the spot joints was performed utilizing the tension-shear configuration. And also evaluate the hardness on the weld spot at the different zone nugget, TMAZ, HAZ and Base plate.**

***Keywords* - Welding, joints, work piece, HAZ And tool.**

1. INTRODUCTION

In late 1991 a very novel and potentially world beating welding method was conceived at TWI. The process was duly named friction stir welding (FSW), and TWI filed for world-wide patent protection in December of that year [1]. TWI (The Welding Institute) is a world famous institute in the UK that specializes in materials joining technology. Consistent with the more conventional methods of friction welding, which have been practiced since the early 1950s, the weld is made in the solid phase, that is, no melting is involved. Compared to conventional friction welding, FSW uses a rotating tool to generate the necessary heat for the process. Since its invention, the process has received world-wide attention and today two Scandinavian companies are using the technology in production, particularly for joining aluminum alloys [2].

A few of the important advantages of FSSW over conventional joining techniques include improved joint properties and performance, low-deformation of the work pieces, a significant reduction in production costs and the freeing of skilled labor for use in other tasks. Compared to the conventional arc-welding of aluminum alloys, FSW produces a smaller heat affected zone, and it also allows the successful joining of aluminum alloys, steel, titanium, and dissimilar alloys with a stronger joint [3].

Despite the initial success of FSSW, there are still many challenging problems that need to be overcome for its fully automated industrial application: the optimization of parameters, the detection of defects, and the control of the process. Extensive experimentation for joining a particular combination of materials helps in determining the process parameters for a particular weld setup [4, 5]. Effort has been concentrated on the modeling of the process in order to predict the thermo-mechanical conditions, to better understand the behavior of the work piece and the conditions which result in successful weld formation and the lowering of residual stresses in the elements. Process monitoring has been undertaken by capturing and processing the acoustic emission during welding for determining the quality of the weld and the status of the FSSW tool (tool wear and tool breakage). Mechanical and micro structural characterization using tensile and optical micrographs and micro-analysis help in classifying the quality of the welds [6, 7 and 8].

Since it was first invented in 1991 by TWI (The Welding Institute), it was apparent that the FSW process was flexible and simple, with many potential advantages, from quality improvements, to cost savings. This was especially evident for materials, such as aluminum, that are difficult to join with traditional processes [9, 11]. The FSW process is inherently simple, with few variables. The basics of the process are illustrated in Figure 1. A

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non-consumable, rotating FSW tool with a specific geometry is plunged into and traversed through the material. The two key components of the tool are the shoulder and the pin (probe) [10, 12]. During welding, the pin travels in the material, while the shoulder rubs along the surface. Heat is generated by the tool shoulder rubbing on the surface and by the pin mixing the material below the shoulder. This mixing action permits the material to be transferred across the joint line, allowing a weld to be made without any melting of the material. The only variables in the process are the rotation speed, travel speed [13].
FSW tool design, and tool orientation and position. Once the proper tool design, rotation speed, travel speed, etc. are selected, this simple process ensures high quality, repeatable welds [14, 15].

2. Tool Geometry

Tool geometry is the most influential aspect of process development. The tool geometry plays a critical role in material flow and in turn governs the downward at which FSSW can be conducted. An FSSW tool consists of a shoulder and a pin as shown schematically in Fig.3.1. As mentioned earlier, 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 the friction between pin and work piece. Some additional heating results from deformation of material. The tool is plunged till the shoulder touches the work piece. The friction between the shoulder and work piece 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 is governed by the tool design. Generally a concave shoulder and threaded cylindrical pins are used [5, 16].

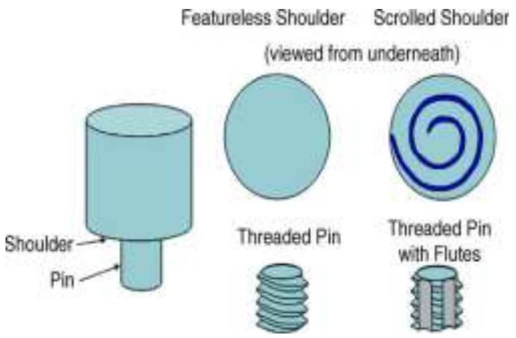

Fig.1. Schematic drawing of the FSSW tool.

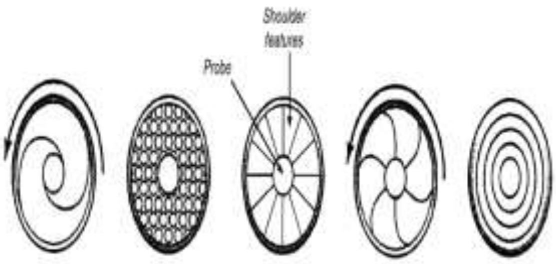

Fig .2. Tool shoulder geometries, viewed from underneath the shoulder.

For lap welding, conventional cylindrical threaded pin resulted in excessive thinning of the top sheet, leading to significantly reduced bend properties. Furthermore, for lap welds, the width of the weld interface and the angle at which the notch meets the edge of the weld is also important for applications where fatigue is of main concern [17].

3. Mechanical Properties

FSSW results in significant micro structural evolution within and around the stirred zone, i.e., nugget zone, TMAZ, and HAZ. This leads to substantial change in post weld mechanical properties. In the following sections, typical mechanical properties, such as strength, ductility, fatigue, and fracture toughness are briefly reviewed below.

This investigation highlights the influence of rotational speed of the tool, and the effect of position of the interface with respect to the tool axis on tensile strength of the friction stir spot welded joint. The axial load is constant between the tool shoulder and the surface of the base material. The rotational speed of the tool axis is continuously changed by keeping the axial load constant. It is found that there is an optimal axial load, above which the weld is defect-free, with joint efficiency of 84% for Al alloy generally. There is a tolerance for interface position; i.e., the tool can be allowed to deviate away from the interface without deteriorating joint efficiency of the weld. The tool can be allowed to deviate from the interface in either side, but the tolerance is higher when the interface is located in the around the tool.

4. Experimental Procedure

The most important control feature is the down force control (Z-axis). It guarantees high quality even if there are tolerances in the materials to be joined. It also enables higher welding speeds, as the down force is main parameter in generating friction to soften the material. The following parameters are to be controlled in Friction Stir spot Welding: Down force, rotation speed of the welding too. So with only two main parameters for the Friction stir spot welding [4, 18].

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The parameters selection was made according to information obtained in the literature. On the basis of report the stir zone width is very narrow using rotational speeds <1000 RPM without dwell time. Therefore, the welds were performed with the lowest rotational speed and also the maximum (RPM, limit of the developed program for FSSW machine) The plunge depth was increased to 1.88 mm, and for these evaluations, only the pin was varied, the choose shoulder was 3 Scrolls, and the rotational speed was 870 &1340 RPM.

Table (1) Main Process Parameters In Friction Stir Welding.

parameter	effects
Rotation speed	Friction heat, “stirring”, oxide layer breaking and mixing
Down force	Friction heat

Table (2) Experimental Parameter.

parameter	range	
Rotation speed	870rpm	1340rpm
Down force	500N	500N

5. VICKERS HARDNESS TEST

(i) The specimen shall be the full thickness of the material at the welded joint and the weld reinforcement and penetration bead shall be left intact. The specimen shall contain a length of the joint of at least 10 mm and shall extend on each side of the weld for a distance that includes the heat affected zone and some base metal portion.
(ii) Specimen after being cut from the plate is filed or ground to obtain flat surface on the specimen.
(iii) Intermediate and fine grinding is carried out using emery papers of progressively finer grades, i.e., of grades, 200 grit, 320 grit, 400 grit and 600 grit (from coarse to fine).

a.

b.

Fig .3. (a) Vicker’s hardness test specimen, (b) Vickers hardness tester [16].

6. TENSILE TEST

Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to uni-axial tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics.

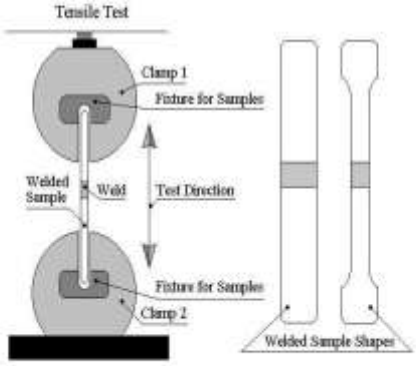


Fig. 4. (a) Tensile Machine, (b) Schematic diagram of tensile specimen and Fixture.

7. Result and Discussion

In this work, a comparative study on the hardness behavior of friction stir (FS) butt welds and Lap joint of 6063 aluminum alloys is carried out. Tensile test of the butt and the lap joint. Vicker's hardness of welded joints and base material (BM) were performed to understand the influence of the Welding process in the static mechanical properties. Micro-hardness profiles were measured and including the BM, the heat affected zone (HAZ) and the welded material (WM).

a. Experimental Result Of Hardness Test

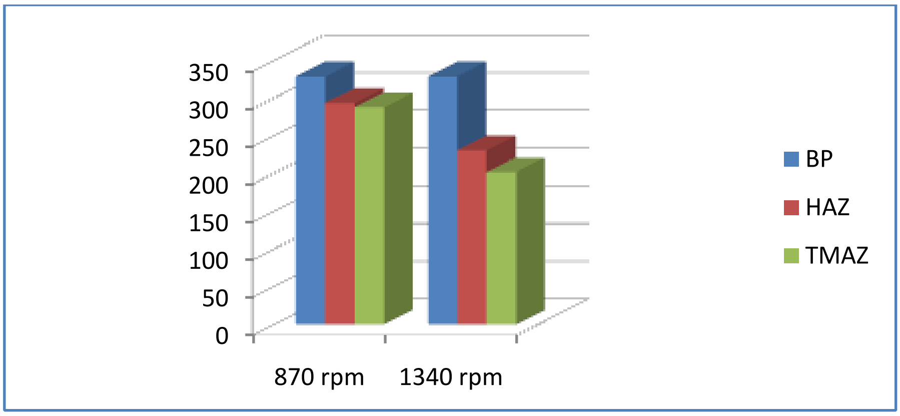
Table (3) Vickers's Hardness Test of Parent Plate, Tmaz, Nugget and Haz for Sample at 870 Rpm for Butt Joint.

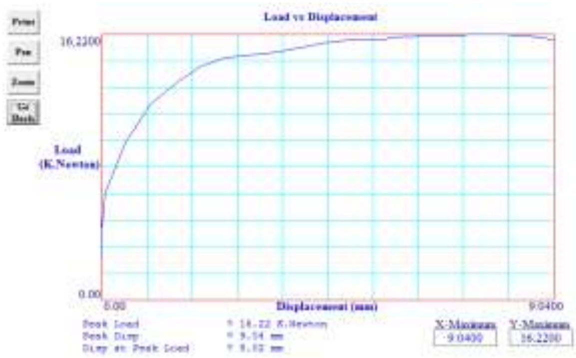
sample no	Reading	Diagonal d(mm)			Test force f/kef(N) 49.03 HV 5			Rotational speed (RPM)	Axial force kN
		BP	***HAZ***	***TMAZ***	***BP***	***HAZ***	***TMAZ***		
S01	A	0.168	0.175	0.181	329	306	286	870	25
	B	0.168	0.179	0.180	329	289	289		
	C	0.168	0.181	0.180	329	286	289		
AVERAGE					329	293.67	288		

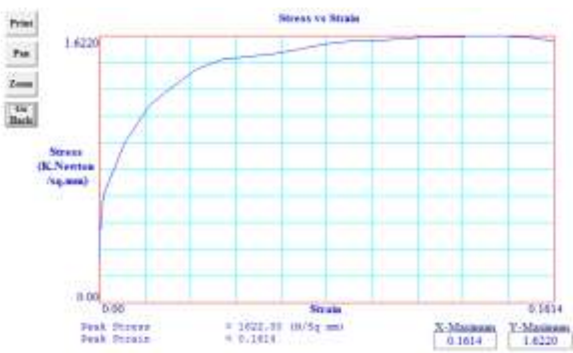
Table (4) Vickers's Hardness Test of Parent Plate, Tmaz, Nugget and Haz for Sample at 1340 Rpm Butt Joint.

sample no	Reading	Diagonal d(mm)			Test force f/kef(N) 49.03 HV 5			Rotational speed (RPM)	Axial force kN
		BP	***HAZ***	***TMAZ***	***BP***	***HAZ***	***TMAZ***		
S01	A	0.168	0.201	0.214	329	232	202	1340	25
	B	0.168	0.203	0.216	329	226	198		
	C	0.168	0.199	0.213	329	234	205		
AVERAGE					329	230.67	201.67		

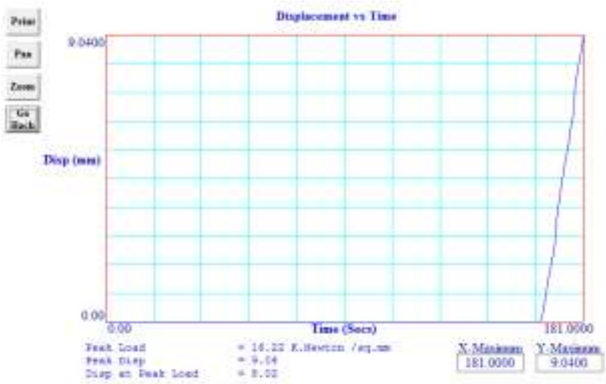
Chart 1. Hardness of Base Plate, Tmaz, Nugget and Haz for Butt Joint at 870 & 1340 Rpm.

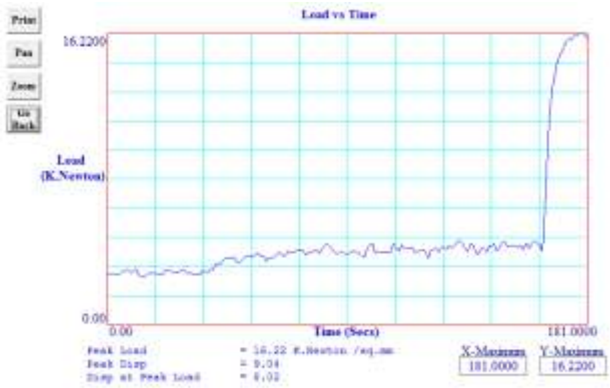






a. b.





c. **d.**

Fig .5. Base plate tesile test graph. (a)load vs displacment, (b) stress vs strain, (c) load vs time (d) displacment vs time.

b. Tensile Test For Butt Joint

Dimesion of the tensile specimen, when the specimen in the jaw of the tensile machine and the cross sectional view shown in figure (a), (b) & (c)

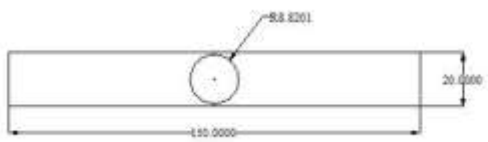


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Figure 6(a).

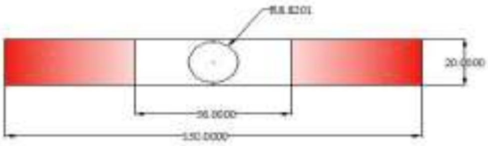


Figure 6(b).

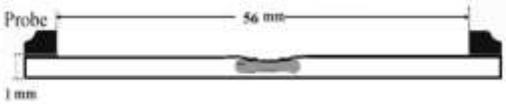
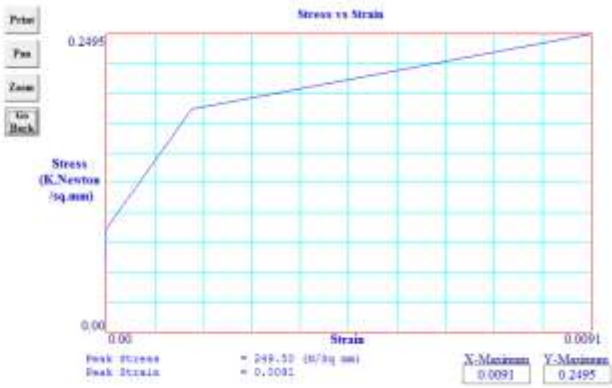


Figure 6(c).

(i) AT 870 rpm.

a.



b.

c.

d.

Fig .7. Tesile test graph for butt weld at 870 rpm. (a) Load vs Displacment, (b) Stress vs Strain, (c) Load vs Time (d) Displacment vs Time.

(ii) AT 1340 rpm.

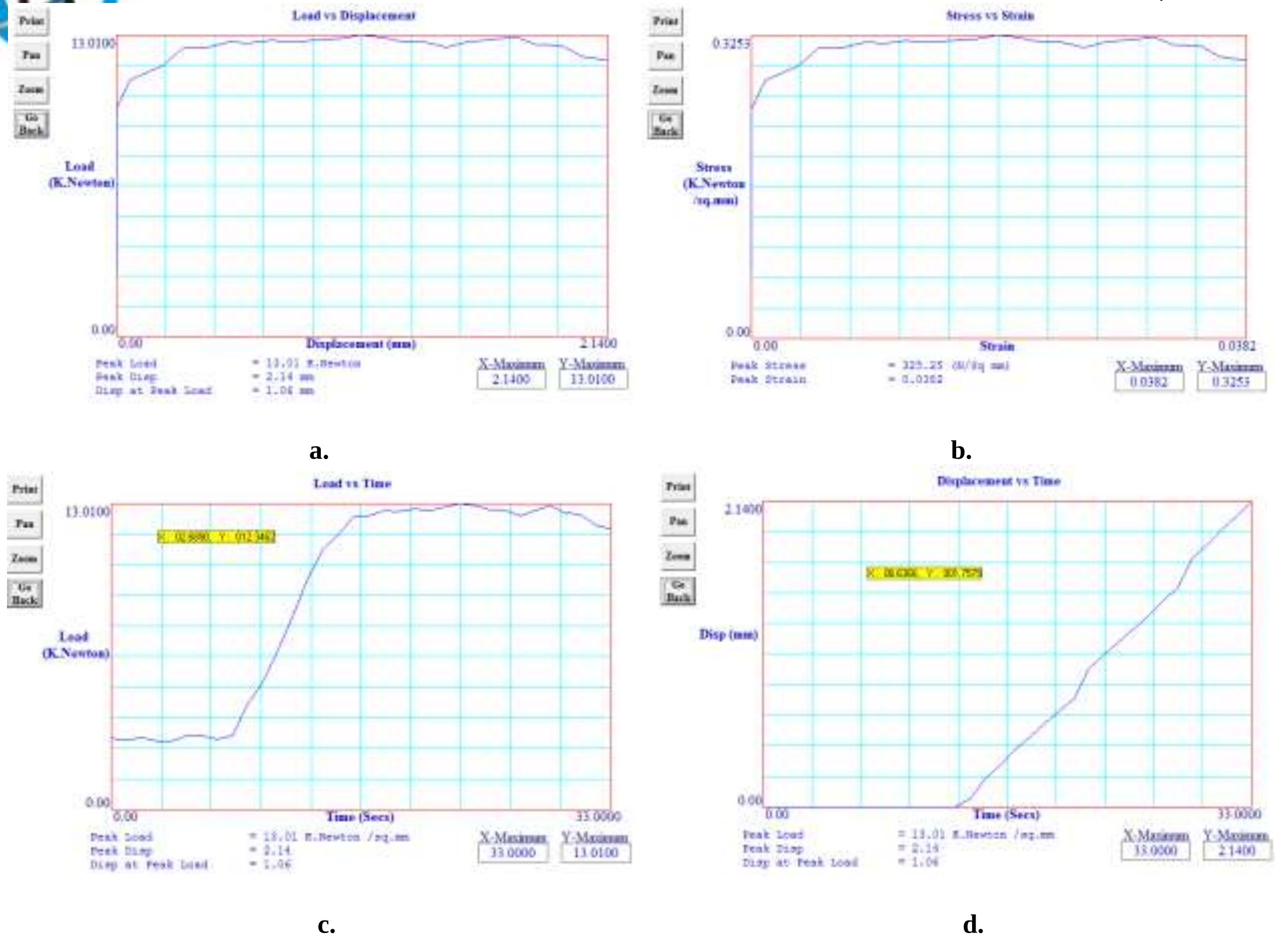


Fig .8. Tesile test graph for butt weld at 870 rpm. (a) Load vs Displacment, (b) Stress vs Strain, (c) Load vs Time (d) Displacment vs Time.

8. Conclusion

A hardness decrease is identified in the TMAZ. The average hardness of the nugget zone was found to be significantly lower than the hardness of the base alloy. There is a zone outside the nugget zone. Which has the lower hardness value. The welding process softened the material reducing the hardness to 33% of the parent material, as shown in chart 4.2.1 and chart 4.2.2. That variation of the micro hardness values in the welded area and parent material is due to the difference between the microstructure of the base alloy and weld zone.

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