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A COMPARATIVE STUDY ON THE HARDNESS BEHAVIOUR OF FRICTION STIR WELDING AA6063 ALLOY

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ABSTRACT

The interest in friction stir welding (FSW) has gained considerable momentum over the past few years. This is because the process has made it possible to implement the advantage of solid-state bonding to aluminum plate and profile joints, thus leading to new product designs previously not feasible. In FSW, the rotating movement of the shoulder and the pin generates the heat. The frictional heating contributes to the formation of a plasticized layer of soft metal beneath the tool shoulder and about the pin. The material is then transported to the flow side of the tool due to the imposed mechanical stirring and forging action before it cools and forms a solid-state joint. In the present investigation, this concept is further developed and applied to FSW is aluminum alloys.
Key words: *friction stir welding, AA6063 alloy, hardness*

1. INTRODUCTION

Friction stir welding (FSW) was invented at The Welding Institute (TWI) of the United Kingdom in 1991. It is a solid-state, hot shear joining technique and initially applied to aluminum alloys [1, 2]. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the butting edges of two rigidly Clamped sheets or plates placed on a backing plate as shown in Fig. 1. The shoulder makes firm contact with the top surface of the work–piece. Heat generated by friction at the shoulder and to a lesser extent at the pin surface, softens the material being welded. Severe plastic deformation and flow of this plasticized metal occurs as the tool is translated along the welding direction. Material is transported from the front of the tool to the trailing edge where it is forged into a joint. The tool shoulder restricts metal flow to a level equivalent to the shoulder position, that is, approximately to the initial work piece top surface. As a result of the tool action and influence on the work piece, when performed properly, a solid-state joint is produced,

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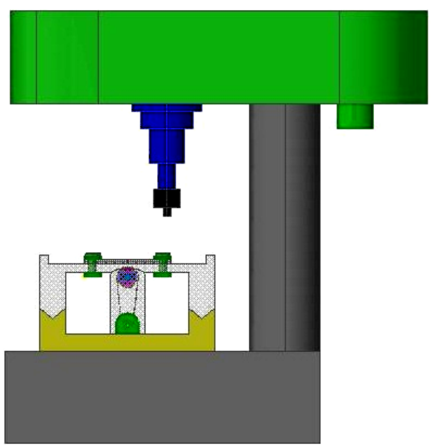
that is, no melting. Because of various geometrical features on the tool, material movement around the pin can be complex, with gradients in strain, temperature, and strain rate [3]. Although Fig. 1 shows a butt joint for illustration, other types of joints such as lap joints and fillet joints can also be fabricated by FSW. Friction stir welding is considered to be the most significant development in metal joining in decades and, in addition, is a “green” technology due to its energy efficiency, environmental friendliness, and versatility. As compared to the conventional welding methods, FSW consumes considerably less energy, no consumables such as a cover gas or flux are used, and no harmful emissions are created during welding, thereby making the process environmentally friendly. Further, because FSW does not involve the use of filler metal and because there is no melting, any aluminum alloy can be joined without concern for compatibility of composition or solidification cracking-issues associated with fusion welding. Over the last decade, friction stir welding (FSW) has offered excellent welding quality to the joining of aluminum, magnesium [4,5], titanium [6] copper [7], Fe alloys [8-10] and also the dissimilar materials, for examples dissimilar Al alloys [11] and aluminum to steel [12-15] with equal ease . FSW can be applied to most geometric structural shapes and to various types of joints, such as butt, lap, T-butt, and fillet shapes [16]. The most convenient joint configurations for FSW are butt and lap joints. Others solid-state welding methods are friction welding [17] and ultrasonic joining [18] have some difficulties. Friction welding has the difficulty that at least one material to be joined should be circular in cross sectional shape. Ultrasonic also has the shortcoming that they are applicable to only thin plate. Layout of friction stir welding machine is shown in Fig.1.



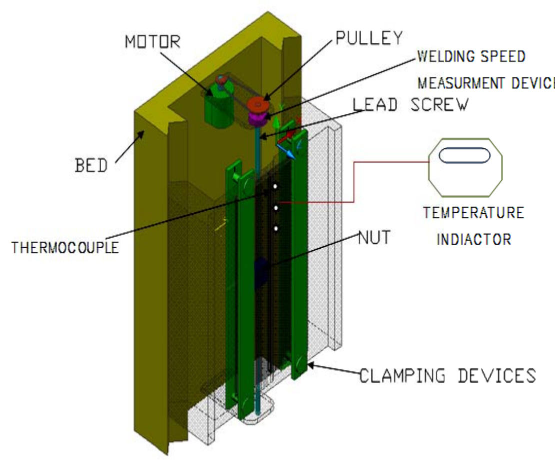


Fig. 1 - D model for FSW machine in side view, front view and bed

2. PILLAR FRICTION STIR WELDING MACHINE

Pillar Friction stir welding also produces a plasticized region of material, but in a different manner. A non-consumable rotating tool is pushed into the materials to be welded and then the central pin, or probe, followed by the shoulder, is brought into contact with the two parts to be joined, Fig. 2. The rotation of the tool heats up and plasticize the materials it is in contact with and, as the tool moves along the joint line, material from the front of the tool is swept around this plasticized annulus to the rear, so eliminating the interface.

Fig. 2 – Pillar friction stir welding Machine.

3. WELDING PARAMETER'S

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 Welding: Down force, welding speed, rotation speed of the welding tool, tilting angle. So with only four main parameters for the Friction stir welding.

Table: 1 - Experimental parameter

	Range	
Rotation speed	*567rpm*	*637rpm*
Tilting angle	0°	0°
Welding speed	$1.00\times 10^{-3} m/s$	$1.59\times 10^{-3} m/s$
Down force	*5KN*	*7KN*

Table: 2 - Chemical Composition of 6063 Aluminium

Element	*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Zn*	*Ti*	*Cr*	*Al*
6063 % Present	*0.2 to 0.6*	*0.35 max*	*0.1 max*	*0.1 max*	*0.45 to 0.9*	*0.1 max*	*0.1 max*	*0.1 max*	*Balance*

Table 3 - Mechanical Properties of Aluminum 6063

Temper	*O*	*T4*	*T6*
Minimum Proof Stress 0.2% (MPa)	*50*	*65*	*160*
Minimum Tensile Strength (MPa)	*100*	*130*	*195*
Shear Strength (MPa)	*70*	*110*	*150*
Elongation A5 (%)	*27*	*21*	*14*
Hardness Vickers (HV)	*25*	*50*	*80*
Elongation A5 (%)	*10*	*5*	

Table 4 - Physical Properties of Aluminum 6063

Property	*Value*
Density	$2.70\times10^3 kg/m^3$
Melting Point	*600°C*
Modulus of Elasticity	*69.5 GPa*
Electrical Resistivity	$0.035\text{x}10^{-6}\ \Omega\cdot m$
Thermal Conductivity	*200 W/m.K*
Thermal Expansion	$23.5\ x\ 10^{-6}\ /K$

4. EXPERIMENT

The friction stir welds were performed in a pillar FSW machine. For both aluminium alloys the same parameters were used: down force 5-7kN, tilting angle 0˚ and rotating speed of 600rpm. The FSW process of the 6063 aluminium alloy was performed using a tool with a 0.5mm diameter threaded pin and the shoulder had 50mm diameter. factors; since alloy type, penetration depth and joint type are the most relevant, these parameters were chosen by trial and error attempts until no visually detected defects could be identified. The penetration depth was adapted to fully penetrated butt joint in a material of 2mm thickness. The process uses a rotating, non-consumable weld tool that plunges into the base material and moves forward. Frictional heat caused by the rotating pin creates a plasticized tubular shaft around the pin. Pressure provided by the weld tool forces the plasticized material to the back of the pin, cooling and consolidating.

5. RESULT AND DISCUSION

In FSW the interaction of a non-consumable and rotating tool with the workpieces being welded, creates a welded joint through frictional heating and plastic deformation at temperatures below the melting temperature of the alloys being joined. Notwithstanding the widespread interest in the possibilities offered by FSW, data concerning the mechanical behavior of joints obtained using this process still is scarce. In this work, a comparative study on the hardness behaviour of friction stir (FS) butt welds of aluminum 6063 alloys is carried out. Vicker's hardness test of welded joints and base material (BM) were performed to understand the influence of the welding process in the static mechanical properties. Microhardness profiles were measured and including the BM, the heat affected zone (HAZ) and the welded material (WM).

6. EXPERIMENTAL RESULT OF HARDNESS TEST

Table 5 - Vickers's hardness test of parent plate, TMAZ and HAZ for sample no. S 01

SAMPLE NO	READING	DIAGONAL d (m)			TEST FORCE F kgf (N) 98.07 HV 10			ROTATIONAL SPEED (RPM)	AXIAL FORCE
		BP	TMAZ	HAZ	BP	TMAZ	HAZ		
S 01	A	0.468×10^{-3}	0.565×10^{-3}	0.505×10^{-3}	84.7	58.1	72.7	600	25 kN
	B	0.467×10^{-3}	0.564×10^{-3}	$0.50.4\times10^{-3}$	85.0	58.3	73.0		
	C	0.470×10^{-3}	0.565×10^{-3}	0.506×10^{-3}	84.0	58.1	72.4		
AVERAGE					84.6	58.2	72.7		

Table 6 - Vickers's hardness test of base plate, TMAZ and HAZ for sample no. S 02

SAMPLE NO.	READING	DIAGONAL d (m)			TEST FORCE F kgf (N) 98.07 HV 10			ROTATIONAL SPEED (RPM)	AXIAL FORCE
		BP	**TMAZ**	**HAZ**	**BP**	**TMAZ**	**HAZ**		
S 02	A	0.474×10^{-3}	0.573×10^{-3}	0.503×10^{-3}	82.5	56.5	73.3	600	25 kN
	B	0.471×10^{-3}	0.575×10^{-3}	0.504×10^{-3}	83.6	56.1	73.0		
	C	0.472×10^{-3}	0.575×10^{-3}	0.504×10^{-3}	83.6	56.1	73.0		
Average					83.3	56.2	73.1		

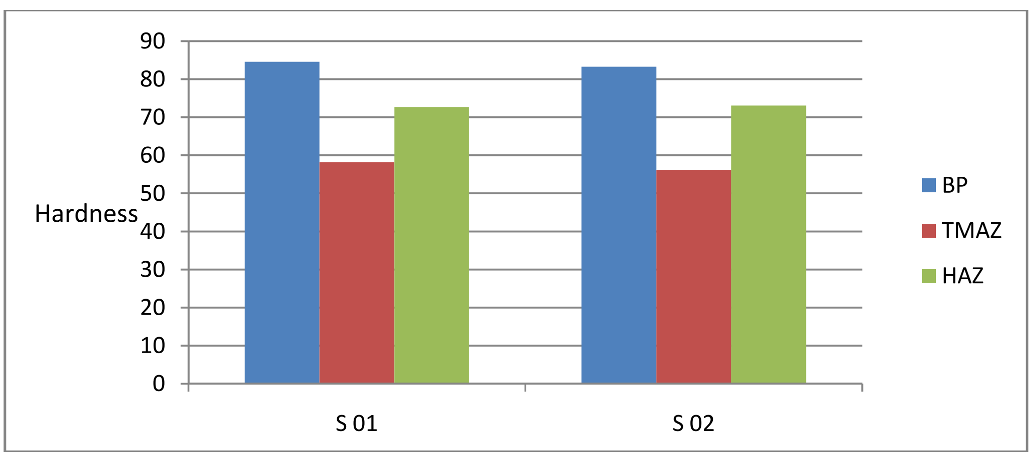


Fig. 3 - Hardness of base plate, TMAZ and HAZ for S 01& S 02

7. 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 that variation of the microhardness 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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KOMPARATIVNA STUDIJA PROMENE TVRDOĆE PRI ZAVARIVANJU TRENJEM LEGURE AA6063

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REZIME

Zavarivanje pomoću trenja poslednjih godina nalazi sve veću primenu u proizvodnom mašinstvu. Glavni razlog za to je što je tim postupkom omogućeno spajanje aluminijumskih limova i profila, u čvrstom stanju što je omogućilo izradu delova koje do tad nije bilo moguće proizvesti. Prilikom zavarivanja trenjem rotacija alata u odnosu na radni komad proizvodi povišenu temperaturu. Zagrevanje usled trenja omogućava formiranje izuzetno plastičnog sloja mekanog metala, koji se zatim hladi i formira čvrst spoj. U radu je šematski prikazan postupak zavarivanja trenjem, kao i detaljan opis eksperimentalnog istraživanja. Tvrdoća je merene na osnovnom materijalu, u samoj zoni zavarivanja i u zoni uticaja toplote (ZUT). U zaključku se navodi da je materijal u zoni zavarivanja omekšao za 33% u odnosu na materijal pre zavarivanja.

Ključne reči: *Zavarivanje trenjem, AA6063 legura, tvrdoća materijala*