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Tensile Strength and Microhardness Behavior of Friction Stir Welded Joints of Magnesium AZ31B-O Alloy

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ABSTRACT

Magnesium AZ31B-0 alloy being considered as extremely attractive lightweight materials for a wide range of the army's future applications where weight reduction is a critical requirement because of its low density. Furthermore, magnesium has good vibration damping capacity. Magnesium alloys have the advantages of low density, high specific strength and excellent damping characteristic, and have become potential structural materials in aerospace and automobile manufacture fields. Magnesium is also highly flammable when it is powdered or shaved into thin strips (such as flash resulting from a weld). The selected material was welded with Friction Stir Welding using combination of different parameters i.e. tool rotational speed (900 rpm, 1200 rpm, 1500 rpm, 1800 rpm and 2100 rpm) and constant welding speed of 45 mm/min. a cylindrical left hand threaded tool with 21 mm tool shoulder diameter and 7 mm pin diameter was employed for welding. The effect of tool rotational speed was examined on the mechanical properties. Microhardness decreases with increase in tool rotational speed due to high heat input. It was observed that excessive heat generation and insufficient flow of plasticized material at higher values of tool rotational speed, leading to formation of defects which ultimately results in failure of weld joints between Stir Zone and Thermo mechanically affected Zone.

Keywords**--** Friction Stir welding, Stir Zone, Ultimate tensile strength, Advancing side (AS) Heat affected zone (HAZ)

I. INTRODUCTION

Friction Stir Welding (FSW) is a solid state welding process first discovered and patented by the Welding Institute of Cambridge U.K. in 1991 by Wayne Thomas et al. and has been since then the subject of a great deal of interest. FSW friction generated by a rotating cylindrical tool to heat and plasticize metal on either side of a joint for obtaining a solid and functional weld. Friction generated heat is more effective at reorganizing the microstructure of metals and metal alloys than other forms of fusion welding. Friction Stir process uses a rotating, non-consumable weld tool that plunges into the base material and moves forward. Friction heat caused by the rotating pin creates a plasticized tubular shaft around the pin [2]. Pressure provided by the weld tool forces the plasticized material to back of the pin. Magnesium alloys are difficult to weld by traditional methods.

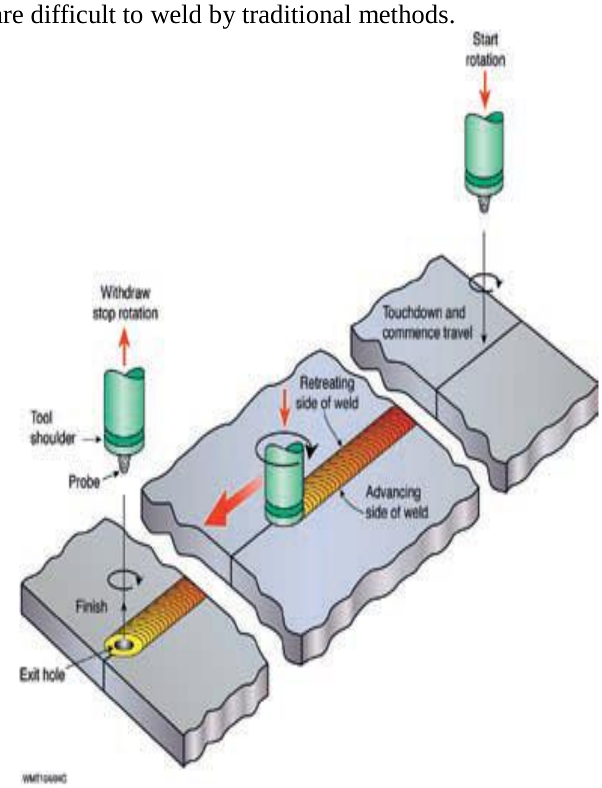

Figure 1: Friction Stir Welding operation

Hence FSW is being increasingly used. The process is especially well suited to butt and lap joint in Magnesium alloy[2]. The present work is aimed to the evaluate the effect of tool rotational speed on mechanical properties of Friction Stir Welded joints of AZ31B-O Magnesium alloy plates.

II. EXPERIMENTAL PROCEDURE

The material under investigation was Magnesium AZ31B-O alloy in the form of rolled plates of 5 mm thickness. Chemical composition of AZ31B-O Mg alloy presented in Table no. 1.

TABLE 1.
CHEMICAL COMPOSITION OF AZ31B-O MG ALLOY

Element	Si	Fe	Cu	Mn	Zn	Al	Ni	Co
Wt %	0.1	0.005	0.05	0.2-0.5	0.5-1.5	2.5-3.5	0.05	0.05

Ten plates of size 150 mm x 75 mm were prepared to obtain five Friction Stir Welded joints with different welding parameters. Plates were welded perpendicular to the rolling direction. The employed tool rotating speeds of the cylindrical threaded tool was 900 rpm, 1200 rpm, 1500 rpm, 1800 rpm and 2100 rpm with constant welding speed of 45 mm/min. A 21 mm tool shoulder diameter with pin diameter of 7 mm and 4.8 mm long was used. Tool profile used in this study was shown in Figure 2.

A cold-work tool High carbon, high chromium oil hardened type steel tool that comprises of outstanding high temperature strength, high temperature toughness, high temperature wear resistance and good machine ability is selected for present work. This tool steel selection was also motivated by its cost and availability [11].

Figure 2: Welding tool profile

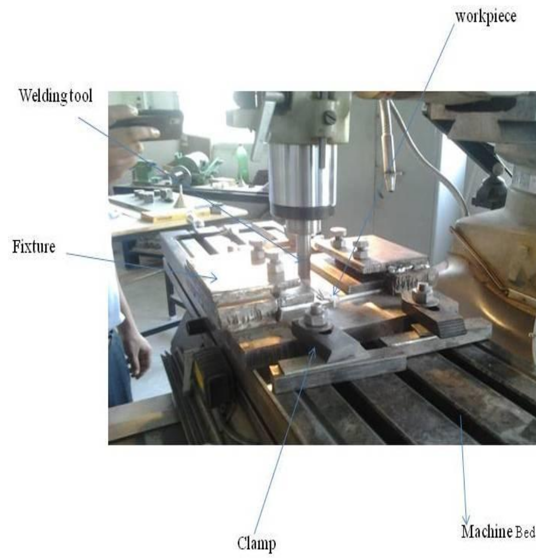

Figure 3: Work piece and fixture set up

For Friction stir welding process cut edges are finished with milling operation so that interfaces can be properly matched. The machine used for the production of the joints was semi automated vertical milling machine. Fixture was first fixed on the machine bed with help of clamps and then plates were held in the fixture properly for Friction Stir Welding as shown in Figure 3. Ten plates of size 150 mm x 75 mm were prepared to obtain five Friction Stir Welded joints at selected tool rotational speeds.

Specimens for the tensile strength analysis cut perpendicular to the weld line as shown in the Figure 4.

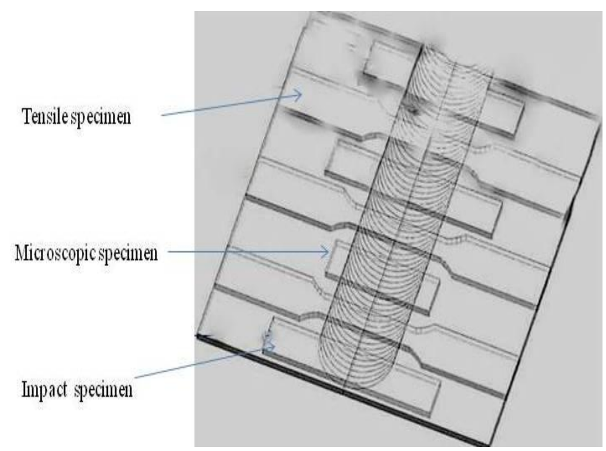

Figure 4: Tested specimen cutting scheme

Tensile test specimens were prepared from each weld in accordance with ASTM specifications, E-8M-08, having specimen of 50 mm gauge length and 12.5 mm width [13]. Tensile test was carried out at a constant speed of 2 mm/min at 16 kN load. The load was applied until the

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necking was there and specimen failed, 20 specimens were prepared from welded joints and 2 specimens were prepared from base material for tensile testing. Servo Control Universal testing machine. Tensile test specimens before and after tensile testing are shown in Figure 5 and Figure 6 respectively.

Figure 5: Specimens before testing

Figure 6: Specimens after testing

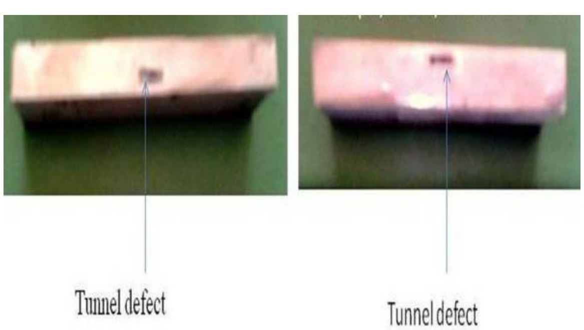

Figure 7: Tunnel defects

Visual inspection was performed on all welded samples in order to verify the presence of macroscopic external defects such as surface irregularities, excessive flash, lack of penetration, voids and surface open tunnel defects [8].The excessive flashes and tunnel defects as shown in Fig. 7 were absorbed at higher rotational speed of 1800 rpm and 2100 rpm due to sufficient stirring and improper interaction of tool shoulder and work piece. Specimens welded with tool rotational speed 900 rpm and 1200 rpm, welding speed 45 mm/min with tool shoulder diameter of 21 mm shows better surface texture as compare to other joints welded at other selected tool rotational speeds. Tool rotational speed of 1200 rpm, 45 mm/min welding speed along with 21 mm tool shoulder diameter was sufficient to join the plates with better surface textures.

III. RESULTS AND DISCUSSION

FSW has become a very effective tool in solving the joining problems of profiled sheets with material continuity, without using different joining methods; particularly in case of aerospace industry, where high ductility and tensile strength are required [7]. In the present work, different FSW butt welds of Aluminium 6063 sheets were successfully obtained by varying the processing parameters.

A. Tensile Characteristics:

The specimens were tensile tested and transverse tensile properties such as Ultimate Tensile Strength (UTS) and percent elongation were evaluated. The four specimens were welded and numbered according to the Table 2 which was followed throughout the study. The specimen 2 exhibits high UTS of 199 N/mm^2
Majority of the specimens were fractured at location between TMAZ and SZ. This is due to the fact that the accumulation of basal slips plane (0001) having their normal parallel to the transverse direction is maximum in that location leading to minimum Schmid Factor [12].

TABLE 2
TENSILE TEST RESULTS

Sr. no.	Rotational speed (rpm)	Welding speed (mm/min)	UTS (N/mm^2)	% elongation
1	900	45	184.5	8
2	1200	45	199	12
3	1500	45	188.6	10
4	1800	45	183.4	8
5	2100	45	179	7

UTS first increases with further increment in rotational rate of 900 rpm to 1200 rpm due to proper heat generation and sufficient material flow from advancing side (AS) to retreating side (RS). The UTS values at rotational speeds of 900 rpm and 1200 rpm at constant welding speed of 45 mm/min with 21 mm tool shoulder diameter were observed 184.5 N/mm^2 and 199 N/mm^2 respectively. A decline in UTS value was observed at higher tool rotational speeds of 1500 rpm, 1800 rpm and 2100 rpm, this is due to the fact that the higher rotational speed leads to high temperature near the threaded pin surface would result in a higher probability for the occurrence of lack of bonding near bottom surface [4]. Thus tunnel defects are observed at high tool rotational speeds due to insufficient material flow [5] from advancing side to retreating side. This is also pointed out that LHT pin tool with clockwise rotations, the plasticized material flow is not a vertical upward but it is a inclined upward from retreating side to advancing side at the trailing side as a result of clockwise rotation. The material flow continuously from bottom of the screw thread to the shoulder of rotating tool. The transported material underneath the shoulder is pushed into a downward direction to fill the cavity at bottom of joint that was already created due to inclined upward flow of material in the vicinity of threaded pin [9][10] .Thus tunnel defects are observed at high tool rotational speeds due to insufficient material flow [8].

B. Effect of tool rotational speed on impact strength

There was an insignificant effect of welding parameters on the impact strength was observed. But slight decrease in impact value was observed at higher tool rotational speed of 1800 rpm and 2100 rpm, due to formation of tunnel defects. Hence high impact strength at the rate of 3 J was obtained with 1200 rpm tool rotational speed. The reduction in impact strength in welded joint, welded with selected tool rotational speed was observed due to formation of tunnel defects [3] .

C. Effect of tool rotational speed on Stir Zone Microhardness

TABLE 3
TENSILE TEST RESULTS

Sr. no.	Rotational speed (rpm)	Welding speed (mm/min)	Microhardness (HV)
1	900	45	66.50
2	1200	45	64.77
3	1500	45	61.07
4	1800	45	51.07
5	2100	45	44.70

The higher value of Micro hardness at the rate of 66.50 Hv was achieved at a tool rotational speedof 900 rpm and at welding speed of 45 mm/min. As the tool rotational speed increases, the heat input increases due to high frictional heat generation, thus the fast cooling rate was achieved at rotational speeds of 1800 rpm and 2100 rpm which provides less time for the grains to grow. The phenomenon of grain refinement has also been observed [6] which showed the result of grain refinement of base material has been achieved through FSP. Although higher tool rotational speeds leads to higher strain rates, which would have produced smaller grain size but the corresponding rise in temperature was found to have a more dominant effect on microstructure It has been also observed that grain size increases with increase in tool rotational speed.

Micro hardness increases with increase in tool rotational speed. This behavior of micro hardness appears due to reduction in grain size with increase in tool rotational speed. The grain boundaries become the main obstacle to the slip of dislocations and the material with smaller grain size would have higher micro hardness or tensile strength as it would impose restriction to the dislocation movement [1].

IV. CONCLUSIONS

In this current research, a study of five tool rotational speeds has been carried out. The tool rotational speed analysis has been carried out on AZ 31B-O Magnesium alloy of 5 mm thick plates. The welding process was carried out at a constant welding speed of 45 mm/min with 21 mm tool shoulder diameter.

UTS increases with increasing tool rotational speed from 900 rpm to 1200 rpm at constant welding speed after it started decreasing under selected parameters. A least values of UTS were observed at 1800 rpm and 2100 due to formation of tunnel defects at high rate of stirring action and increase in size of TMAZ and HAZ region. Most of the welded joints were fractured in a area between SZ and TMAZ towards AS because of softening point at this point. A 45^0 fracture angle was observed in the majority of joints. Defects were observed near the bottom surface of the SZ.

Micro hardness decreases with increase in tool tool rotational speed from 900 rpm to 2100 rpm Selected tool material i.e. High chrome high carbon steel withstands at high tool rotational speed and performs Friction Stir welding with negligible wear.

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