International Journal of Applied Research in Mechanical Engineering

Volume 2 | Issue 4 Article 4

April 2013

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INFLUENCE OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES OF FRICTION STIR WELDED AA 6061-T6 ALLOY AND MG AZ31B ALLOY

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Abstract- The present study investigates the influence of tool pin profiles on microstructure and mechanical properties of friction stir welded AA 6061-T6 Alloy was studied. An attempt is made here to review the fundamental principle of this process its tensile strength and examination of its metallurgical consequences. An improved milling machine is fabricated for performing friction stir welding and its effectiveness in joining Al 6061-T6 Alloy plates is demonstrated in the current work. The FSW Process has proved to be very efficient and has immense potential for future application. Present investigation is to find out the optimum mechanical properties of friction stir welding of Al 6061-T6 alloy &Mg AZ31B alloy. In this present study an attempt has been made to study the effect of tool rotational speed, traversing speed and tool pin profiles (Taper Thread profile) on FSW zone transformation in Al and Mg alloys. For three different tools, rotational speeds, three different traversing speeds, and three different tool D/d ratios, one tool pin profile have been used to fabricate the joints. The formation of FSW of Al 6061 of fusion zone has been evaluated and correlated with base metal. Tensile properties, toughness and microstructure of the joint were evaluated and correlated as received Al 6061-T6 & Mg AZ31B alloys. The joints fabricated using rotational speed of 1120rpm, a welding speed of 40 mm/min, taper thread pin profile, tool shoulder diameter of 18 mm, (D/d)=3.0 showed higher tensile properties compared to other joints.

Keywords- *Friction stir Welding; Al 6061 AZ31B Mg alloy; Mechanical properties; Rotational speed; Welding speed*

1. INTRODUCTION

Friction stir welding (FSW) is a solid-state joining process using frictional and adiabatic heat generated by a rotating and traversing cylindrical tool with a profiled pin along a square butt weld joint. The advantages of the solid-state FSW process also encompass better mechanical properties, low residual stress and deformation, weight savings, and reduced occurrence of defects [1, 2]. The FSW was first developed in 1991 by The Welding Institute (TWI), and ever since, the FSW studies have been mainly focused on the joining of Al alloy systems [3,4], which has the greatest demand in various industries over conventional welding processes. In this study, the microstructure of Al 6061-T651 alloy welded by FSW method was investigated. The main focus was to examine the texture evolution, grain size change and grain boundary characteristics with respect to the welding parameters of advancing and rotating speed.
In recent years, demands for light-weight and/or high strength sheet metals such as aluminium alloys have steadily increased in aerospace, aircraft, and automotive applications because of their excellent strength to weight ratio, good ductility, corrosion resistance and cracking resistance in adverse environments.

During FSW process, the rotating tool induces a complex deformation in the surrounding material that varies as a function of welding condition [3-5]. Recrystallization of the microstructure takes place under severe plastic strain and elevated temperature due to FSW process, usually resulting in a very fine-grained structure in the weld zone. It is therefore expected that the complicated microstructure around the weld zone would govern the fatigue property of FSW joints. However, the fatigue behaviour of FSW joints is still unclear [6-7]. In the present study, the fatigue behaviour of FSW joints of 6061-T6 aluminium alloy was investigated. The 6061-T6 plates were joined under different welding conditions. Fatigue tests were conducted at stress ratio R = 1 under axial loading and the effects of microstructure on fatigue behaviour were discussed.

However, there is no result reported in the literature related to combination welding speed and rotational speed, which influence on mechanical properties of FSWed Al 6061 and AZ31B Mg alloy. In this present investigation, effect of rotational speed (i.e. 900 rpm, 1120 rpm, and 1400 rpm) and welding speed and D/d)=3.5 on mechanical properties of friction stir welded of Al 6061 and AZ31B Magnesium alloy of the microhardness and mechanical properties are evaluated.

2. EXPERIMENTAL WORK

Rolled plates of 5 mm thickness AA 6061-T6 alloy were cut to the required dimensions (240mm×60 mm×5mm) by wire cut Electric Discharge Machine.

The schematic diagram of Al 6061 alloy plates used for FSW is shown in Fig.1. The chemical composition of base metal is presented in Table 1.The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding is normal to the rolling direction and single pass FSW used to fabricate the joints. The diameter of the tool shoulder (D) is 18 mm and that of the insert pin diameter (d) and pin length (L) are 6 mm and 4.8 mm respectively. The schematic diagram of Tool geometry is shown in Fig.2. The FSW parameters such as tool rotational speeds, travelling speed and shoulder to pin diameter were 900 rpm, 1120 rpm, and 1400rpm, with 40mm/min and 3.0 respectively. The tool onward tilted an angle of 2.5^0 and a vertical load of 5KN is applied. The FSW process parameters and tool nomenclature are presented in Table 2.The process is carried out on a vertical milling machine (VMM) (Make HMT FM-2, 10hp, 3000rpm). The macrographs of VMM and tool arbor are shown in Fig.3 and Fig.4 respectively. For various testing the required dimensions of the specimens were cut from the region under the tool shoulder (i.e. stir zone) by using wire EDM. The specimens for metallographic examination were sectioned to the required size and then polished using different grades of emery papers. A standard Kellars reagent made of 3 ml Hydrofluoric acid, 2ml acetic acid, 10 ml diluted water, and 70 ml distilled water was used to reveal the microstructure of the welded joints. Micro structural analysis was carried out using a light optical microscope (Maker: Metzer-M, Binocular Microscope; model: METZ-57) incorporated with an image analysing at high magnification to estimate the weight percentage of elements.

The smooth tensile specimens were prepared as per ASTM: E8/E8M-11 standard to evaluate yield strength, tensile strength, and elongation of the joints. The schematic diagram of the tensile specimen is shown Fig.6. Tensile test was carried out in a 100 KN electromechanical-controlled universal testing machine (maker: FIE-Bluestar, India; model: TUE-600C). Tensile testes of as-received Mg alloy and the FSWed joint were determined at ambient temperature and three specimens were machined from each joint and the average was reported.

The charpy impact specimens were prepared according to the ASTM: E23-06 standard and evaluate the impact toughness of the weld metal and stir zone, and hence the notch was placed (machined) at the weld metal (weld centre) as well as in the SZ. The schematic sketch of charpy impact specimen is shown in Fig.7.

Impact testing was conducted at room temperature using a pendulum type impact testing machine with maximum capacity of 300 J.

Table 1: Typical chemical composition of the alloy AA6061-T6

Element	Al	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	Others
Amount (Wt %)	Bal	0.8-1.2	0.4-0.8	Max. 0.7	0.15-0.40	Max. 0.25	Max. 0.15	Max. 0.15	0.04-0.35	0.05

Table.2. Chemical composition (wt %) of base metal AZ31B magnesium alloy.

Al	Mn	Zn	Cu	Ni	Si	Fe	Mg
3.0	2.0	1.0	0.05	0.005	0.1	0.005	Balance

Table.3. Chemical Composition of H13 Tool Steels

C	Cr	Mn	P	S	V	Mo	So	Ni	Cu
0.32	4.85	0.30	0.030	0.030	0.9	1.1	0.8	0.3	0.25

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Fig.1Picture of Verticle Milling Machine(VMM)

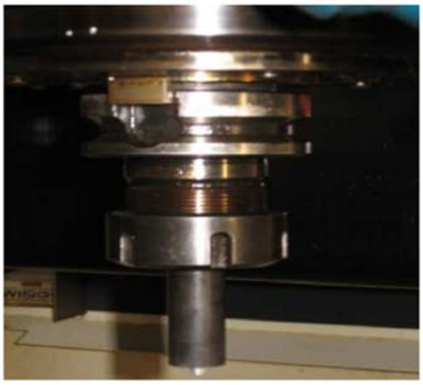


Fig.2 Picture of VMM Tool Arbor

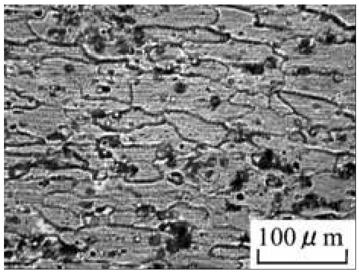
Figure.3. Al-Al weld joint at 900 rpm, speed,3 D/d ratio

Figure.4. Mg-Mg weld joint at 1120rpm, 40mm/min weld 25 mm/min weld speed,3 D/d ratio

3. RESULTS AND DISCUSSIONS:

3.1. Microstructure:

The optical micrographs taken at stir zone of FSW of all the joints are displayed in Fig.6 (A-I).From the micrographs, it is understood that there is in appreciable variation in average grain diameter of weld region in Al 6061 and AZ31B Magnesium alloy. Due to FSW, the coarse grains of base metal are changed in to fine grains in the stir zone. The joints fabricated with a rotational speed of 1120 rpm with a constant welding speed of 40 mm/min and SS tool contain finer grains in the weld region compared to other joints. In FSW, tool rotation speed results in stirring and mixing of material around the rotating pin which in turn increase the temperature of the metal. When the rotational speed increases, the heat input within the stirred zone also increases due to the higher friction heat which in turn result in more intense stirring and mixing of materials[8]. For the given the increase in rotation speed beyond made of SS tool 1120 rpm produces very fine grains the detailed microstructure is observed in fig.6 The heat input and material flow behavior decides the quality (defective or defect free) of FSW joints. The heat input and material flow behavior are predominantly influenced by the FSW process parameters such as tool rotation speed, welding speed and axial force. The heat input increases with increase in rotation speed. At lower rotation speed, the heat input is not sufficient and also improper stirring causes a tunnel defect at the middle of the retreating side. Higher rotation speeds could raise the strain rate and turbulence (abnormal stir- ring) in the material flow caused a tunnel defect at the weld nugget. As the rotation speed increases, the strained region widens, and the location of the maximum strain finally moves to the retreating side from the advancing side of the joint. This implies that the fracture location of the joint is also affected by the rotation speed.



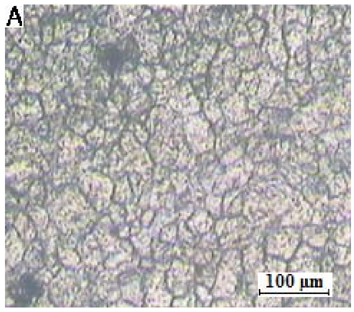


Fig.6.(a)Base metal Al 6061 alloy (b) Base metal Mg AZ31B alloy

Fig. 6.c Al-Al
rpm: 900
feed: 40
D/d: 3

Fig 6.d Al-Al
rpm: 900
feed: 40
D/d: 3.5

Fig. 6.e.Al-Al
rpm: 1120
feed: 40
D/d: 3

Fig.6.f.Mg-Mg
rpm: 1120
feed: 40
D/d: 3

Fig.g. Al-Al
rpm: 1120
feed: 40
D/d: 3

Fig.h.Al-Al
rpm: 1400
feed: 40
D/d: 4

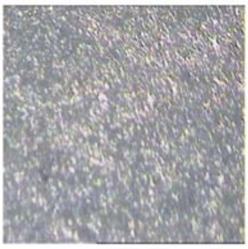


Fig.i. Mg-Mg
rpm: 1400
feed: 40
D/d: 3

4. RESULTS AND DISCUSSION

4.1 Effect of tool rotational speed on Mechanical Properties

Transverse tensile properties such as yield strength, tensile strength and percentage of elongation of the FSW have been evaluated at each condition two specimens are tested and average of the results of two specimens is presented in below table. From the table, it can be infrared that tool rotational speed, welding speed and D/d ratio are having influence on tensile properties of the FSW joints. Of the 7 joints, the joints fabricated by taper threaded at joint 3 exhibited superior tensile properties compared to other joints.

Table.6.Effect of Rotational speed on tensile properties

S. NO	Speed (rpm)	Tensile strength(N/mm^2)	Yield stress(N /mm^2)	Elongation
1	900	138.97	89.004	4.32
2	900	165.94	112.91	8.48
3	1120	168.05	122.35	8.79
4	1120	122.63	97.344	1.92
5	1400	143.73	111.06	5.11

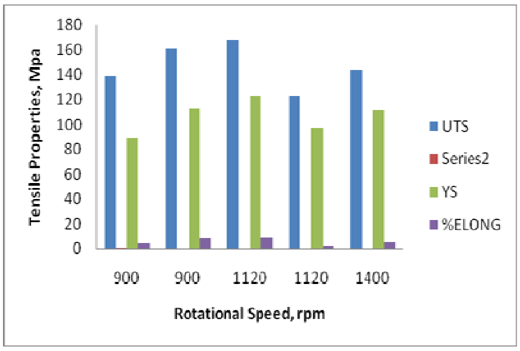


Fig.7.Effect of rotational speed on tensile properties

From the above table revels that the effect of rotational speed on tensile strength of friction stirs welded Al 6061 alloy joints. At lower rotational speed (900rpm), the tensile strength of FSW joint is low when the rotational speed increased from 900rpm, correspondingly the tensile strength also increase and reaches maximum at 1120 rpm if the rotational increased above 1120 rpm, the tensile strength of the joint is decreased. Higher tool rotational speed (1400 rpm) usually resulting in higher heat input per unit length and slower cooling rate in the FSW zone causes excessive grain growth which subsequently leads to lower tensile properties of the joints. a higher rotational speed also causes excessive release stir materials to ht upper surface, which resultantly produces micro voids in the stir zone and this may be one of the reasons for the lower tensile properties if the joints. At lower rotational speed 900rpm results in lack of stirring due to lower heat in put per unit length, which results in inadequate plasticization and this is also one of the reason for lower tensile properties of the joints [8].the joint fabricated at tool rotational speed of 1120rpm exhibited maximum tensile strength this may be due to optimum heat generation which is sufficient to cause free flow of plasticized material and adequate mechanical properties.

4.2 Effect of welding speed on tensile strength

Figure (5.3) reveals that effect of welding speed on tensile strength on friction stir welded Al 6061 alloy joints. At lower welding speed 25mm/min, the tensile strength of FSW joint is higher. when the welding speed from 25mm/min correspondingly increases the tensile strength increase and reaches maximum at 80mm/min. Higher welding speeds 80mm/min,40mm/min result in short expose time in weld area with sufficient heat and good plastic flow of the metals and causes defect free joints .Lower welding speed 25mm/min results in higher temperature and slower cooling rate in weld joint causes excessive grain growth, which subsequently may lead to lower tensile properties of the joints[9].The joint fabricated at welding speed of 80mm/min exhibited maximum tensile strength this may be due to optimum heat generation which is sufficient to cause free flow of plasticized material and adequate mechanical properties.

4.3 Effect of D/d ratio on tensile strength

Below graphs reveals that effect of welding speed on tensile strength on friction stir welded Al6061 & Mg AZ31B alloy joints. At lower D/d Ratio i.e at 3, the tensile strength of FSW joint is lower. When the D/d ratio from 3 correspondingly increases the tensile strength increase and reaches maximum.

higher D/d ratios 4, 3.5 result in large expose shoulder diameter in weld area results in sufficient heat and good plastic flow of the metals and causes defect free joints .the joint fabricated at D/d ratio exhibited maximum tensile strength this may be due to optimum heat generation which is sufficient to cause free flow of plasticized material and adequate mechanical properties.

From the above table the values obtained shows that we have obtained maximum impact strength at joint 4 with rotational speed: 1120 rpm, welding speed:

40mm/min, D/d ratio: 3.The least impact strength was obtained for the joint 1 with rotational speed: 900 rpm, welding speed: 25 mm/min, D/d ratio: 3.

Table.8. Comparison of tensile properties of Al 6061 and Mg AZ31B

S.No	Tool material	Tool geometry	Rotational speed (rpm)	Weld speed (mm)	D/d ratio	Ultimate tensile strength N/mm^2	Yield stress N/mm^2	Percentage of elongation (%)	Impact strength (joules)
Joint 4(Mg-Mg)	H13	Taper threaded	1120	40	3	145.92	116.04	2.36	26
Joint 5(Al-Al)	H13	Taper threaded	1120	40	3	122.63	97.344	1.92	9

Above table shows that the mechanical properties of Al 6061-T6 and Mg AZ31B.The above comparison has taken place at constant welding parameters that at rotational speed, welding speed and D/d ratio. We obtain better tensile properties for Mg AZ31B alloy due to its good weldability, low density, high ultimate tensile strength, and high yield stress.

5. CONCLUSION

The tool geometry and rotational speed have been identified as the important parameters that affect the stir zone microstructure and properties of Friction Stir Welding (FSW) process. The following conclusions can be obtained.

- The low rotational speeds provided high stirred zone micro hardness values compare to the base material. There exists a particular combination of tool rotational and tool material at which high strength properties may be achieved in the stir zone
  The joint fabricated at a tool rotational speed of 900 rpm have shown lower ultimate tensile strength, yield strength, percentage of elongation and impact test compared to the joints fabricated at a tool rotational speed of 1120rpm
- The joint fabricated at a rotational speed of 900rpm and 1400 rpm have also shown lower tensile strength properties compared to the joints fabricated at a rotational speed of 1120 rpm
- Of the seven joints fabricated using three different welding parameters, the joint fabricated using weld parameters as rotational speed of 1120rpm, 25mm/min weld speed and 3 as D/d ratio exhibited superior tensile strength properties.

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