IMPACT AND BENDING CHARACTERISTICS OF FRICTION STIR WELDED AA6061T651 - AA7075T651 BUTT JOINT

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Abstract

Aluminium alloys have gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to weight ratio and good corrosion resistance. Modern structural concepts demand reductions in both the weight as well as the cost of the production and fabrication of materials. Compared to the fusion welding processes that are routinely used for joining structural aluminium alloys, friction stir welding (FSW) process is an emerging solid state joining process was invented in 1991 by TWI, in which the material that is being welded does not melt and recast. The major advantage in FSW process is that the maximum temperature reached is less than 80% of the melting temperature (TM), i.e. the joint is performed in the solid-state and excessive micro structural degradation of the weld zone is avoided. This process uses a non-consumable tool to generate frictional heat in the abutting surfaces. The welding parameters such as tool rotational speed, welding speed, axial force etc., and tool pin profile play a major role in deciding the joint strength. This paper focus on Impact and Bending Characteristics for friction-stir welded dissimilar precipitation hardenable aluminium alloys between 6xxx (Al-Mg-Si) and 7xxx (Al-Zn-Mg) in varying the process parameters such as rotational speed, welding speed keeping axial force and tilt angle (0°) as constant. Three different tool profiles (taper cylindrical threaded, taper square threaded and Simple Square) are used for this investigation and in that taper cylindrical threaded tool give good result in evaluating impact and bending strength of the above dissimilar butt joints.

Keywords— Bending strength Dissimilar Aluminium alloys, Impact strength, Pin profiles.

I. INRODUCTION

N recent years, demands for light weight and high strength sheets such as aluminum alloys have increased steadily in aerospace, aircraft and automotive applications due to their extra-ordinary strength to weight ratio with their resistance properties in adverse environments. Friction stir welding (FSW) process is a solid state joining technique considered to be the significant development over the past two decades which was invented and validated at the welding institute (TWI), United Kingdom in the year 1991[1].The FSW process is explained using Fig.1.It gives the conceptual idea of friction stir welding process for the two plates with butt joint configuration. In this process a non-consumable tool is to be plunged into the faying surfaces of the plates with rotation and also it moves along the joint line for weld consolidation. The joint integrity depends upon the tool geometry nature used in this process. The tool pin and shoulder are helpful for heat generation, and material mixing by stirring producing the joint. In this process no melting occurs and the heat is generated internally by means of friction between the material-tool interface and the plastic deformation takes place without pre or post heating. Materials with different aluminium alloys can be welded together with a least alteration in mechanical properties due to no melting. Material flow mechanism explained with the dominant parameters rotational speed, welding speed and axial force [2]. There are two different modes of material flow regimes involved in the friction stir weld formation; namely “pin-driven flow” and “shoulder-driven flow”. These two material flow regimes merge together to form a defect-free weld. Studies have been conducted to characterize the result of microstructure in welds especially in aluminium alloys where the weld nugget was fully recrystallized with good material flow [3-4]. In the FSW process, parameter selection and tool geometry are among the key factors that determine the quality of the fabricated joint. Adjusting the values of different parameters, such as welding speed, rotational speed, tilt angle, and pin geometry, could lower the forces exerted from the TMAZ section to the tool. The plastic flow is responsible for obtaining a weld with high tensile strength and fewer defects and therefore the tool geometry plays an important role in achieving a high-quality weld. K. Elangovan et al [5] referred out

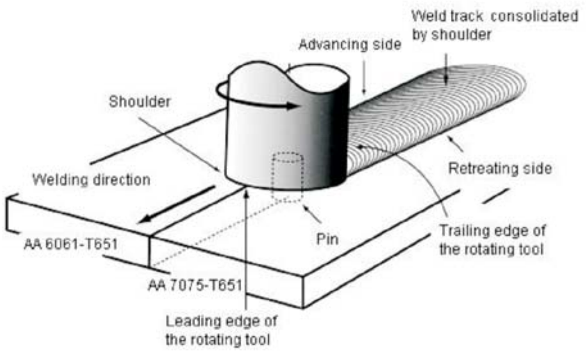

Fig. 1 Schematic diagram of friction stir welding

of the three welded joints, the joints fabricated by FSW process exhibited higher strength values and the enhancement in strength value is approximately 34% compared to GMAW joints, and 15% compared to GTAW joints. P Bahemmat et al [9] investigates the mechanical, micro- and macro structural characteristics of the friction-stir welded dissimilar joints of AA6061-T6 and AA7075-T6 alloys. This research reveals that there are severe defects in the joint fabricated at a welding speed of 160 mm/min. In addition, some small defects are found at higher magnification in the joints made at a speed of 120 mm/min. Many studies have been conducted to characterize the resulting microstructure in welds especially in dissimilar aluminium alloys [6-8]. Many researchers studied and reported he base materials microstructure and its properties [10-11]. However, there are not enough literatures on impact and bending characteristics of dissimilar materials especially on aluminium alloys between 6000 and 7000 series. The aim of this paper is to present and report the results of impact and bending characteristics of dissimilar welds of aluminium alloys between AA7075-T651 and AA6061-T651 produced at different welding parameters.

II. EXPERIMENTAL SETUP

The Friction stir welds between AA7075-T651 and AA6061-T651 aluminium alloys were produced at Coimbatore Institute of Technology, Tamilnadu, India using FSW machine with specification (Hydraulic power pack motor of 2.2 kW /440V with 3000 rpm maximum rotational speed; 5000 mm/min as X-axis rapid traverse speed and maximum axial thrust as 50 kN). The thicknesses of both plates were 6.35 mm. The plates were in a butt joint configuration and the welding process was carried out normal to the rolling direction of the plates .The dimensions of the aluminium alloy plates are 100mm length and 50 mm width. The welding process was accomplished at three rotational speeds,800,900 and 1000 rpm, three welding speeds, 90,100 and 110 mm/min keeping axial load 12 kN and tilt angle as 0° as constant. AA 6061-T651 placed in Advancing side whereas AA7075-T651 in retreating side. Three different pin profiles (Taper cylindrical threaded (TCT), Taper square threaded (TST) and Simple Square (SS) tools used were machined from H13 tool steel and hardened to 55HRC.Studies of the bending and impact properties of base alloys were carried out and the values are tabulated in Table 1 & Table 2. The bend tested specimen size are $300 \times 40 \times 6.35$ mm whereas the impact tested specimen dimension are $10 \times 10 \times 55$ mm for base alloys. Based on Box-Behnken design matrix 15 joints (3-factors, 3-Levels) were welded with the above range of parameters with three various pin profiles to evaluate the bending and Impact characteristics. AA 6061-T651 placed in Advancing side whereas AA7075-T651 in retreating side. The three pin profiles photo copy, FSW machine are presented in Fig.2. Impact and bend tested machine are presented Fig.3.

Table 1 Bending strength for base aluminium alloys

Material	Angle of bend (Deg)	Mandrel Dia (mm)	Remarks
AA6061-T651	180	4T	No cracks or fissures observed
AA7075-T651	180	4T	Broken into two halves

Table 2 Impact strength for base aluminium alloys

Material	Charpy test	Test temperature	Absorbed energy in Joules
AA6061-T651	V-Notch	25°C	6
AA7075-T651	V-Notch	25°C	2

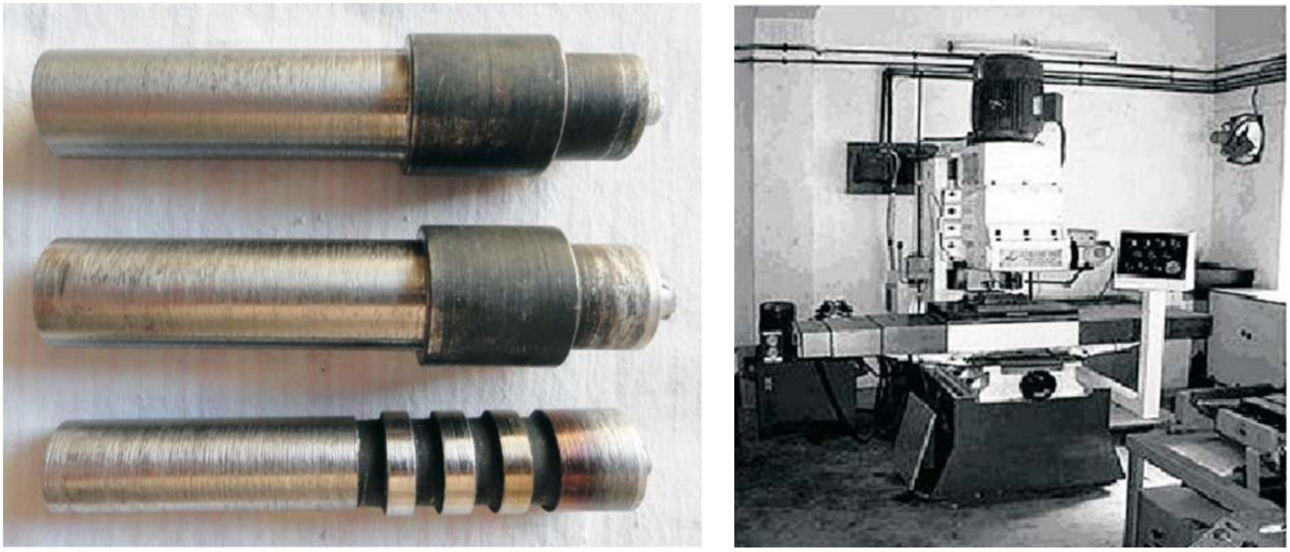

Fig. 2 (a) Three pin profiles used for experiments (b) FSW machine

Fig. 3 (a) Impact testing machine (b) Bending testing machine

III. RESULTS AND DISCUSSION

A. Bending characteristics of the welds

In the FSW process, three factors contribute to the formation of the joints. The first is the temperature difference in the welding region, which softens the BMs in the SZ. The second factor is the stirring of plastic materials in accumulating multi-layer plasticized materials behind the tool, by the interaction of rotational and welding speeds and the pin profile. The last element is forging of plasticized materials conducted by the tool shoulder. Any inappropriate adjustment of these factors results in defective joints. In this experiment, the ratio of the shoulder diameter to the pin diameter was assumed to be constant and, therefore, the only parameter affecting the temperature rise in the welding zone was the welding speed and Rotational speed. Since the temperature increase at the welding speed of 110 mm/min was not enough to soften the base material, the materials were not sufficiently plasticized to be stirred and forged easily for all the pin profiles resulting lesser bending strength. Defect was in the root for all the joints fabricated. This defect is known as the Tunnel hole defect. Though the appearance of the welded surface seems to be good, tunnel defects could be observed at the advancing side and the stirred zone of the weld. The plastized metal under the shoulder cannot flow sufficiently during the

Fig. 4 The cross section of a FSW weld (900rpm, 90mm/min); 'A' denotes HAZ at AS; 'B' is the TMAZ at AS; 'C' is the SZ; 'D' is the TMAZ at RS; 'E' is the HAZ at RS; showing tunnel defect.

welding process due to insufficient heat generation. This problem can be alleviated by optimizing the process parameters, particularly by reducing the welding speed and increasing the rotational speed and the depth of the pin penetration in the BMs. At the welding speed of 90 mm/min, rotational speed 900rpm, with the Taper cylindrical threaded tool the temperature did increase enough, so the BMs adequately soften to go higher bending strength. A noticeable point is that AA6061 and AA7075 alloys are classified into heat-treatable (precipitation-hardenable) alloys and the hardness profile in these alloys is strongly affected by the precipitate distributions rather than the grain size. So precipitate dissolution and coarsening make the hardness of the SZ become less than the hardness of the BMs. Although the TMAZ undergoes plastic deformation, recrystallization usually does not occur in this zone owing to insufficient deformation strain. HAZ experiences a thermal cycle but does not undergo any plastic deformation the predicted peak temperature is between 80 to 140 deg C. Typical bending specimens and bended specimens are shown in Fig.5.

Fig.4 shows the typical cross section for joint zonal areas with tunnel defect with rotational speed 900rpm and welding speed 90 mm/min. The bending tests are carried out as per ASTM E-290-08 for welded specimen to check ductility and weld consolidation. The dimensions for the bending specimen are $100 \times 12 \times 6.35$ mm. For each joint face and root bends are checked with mandrel diameter 4T for 180°.

The experimental bending results for both face and root bend for the 15 combinations of process parameters are listed in Table 3.

B. Impact characteristics of the welds

At the welding speed of 90 mm/min, rotational speed 900 rpm, with the Taper cylindrical threaded tool the temperature did increase enough, so the BMs adequately soften to go higher Impact strength. Since the temperature range also less the base alloys are not soften with stirring. The materials are not thoroughly mixed during the welding process. If we go for lower welding speed in the range 90 mm/min and the rotational speed 900 rpm we can get the high impact and bending strength for Taper cylindrical threaded tool pin profiles combinations. The specimens are mostly failing at the HAZ of the advancing side of 6061 which have the lowest hardness values.

The experimental Impact results for the 15 combinations of process parameters are listed in Table 4.

Fig. 5 (a) Typical bending specimens (b) Typical bend tested specimens after testing

Table 3. Bending strength for experimental combinations

Joint No	Face/Root Bend	Ult.Load in kN	Disp.at F max in mm	Max.Disp in mm	Area in mm^2	UTS in N/mm^2
1-TCT	Face bend	2.78	6.4	17.5	83.49	0.033
	Root bend	2.73	3.7	4.1	83.49	0.033
2-TCT	Face bend	3.29	8.4	8.5	83.49	0.039
	Root bend	1.33	0.3	3.2	83.49	0.016
3-TCT	Face bend	0.075	0.1	2.3	83.49	0.001
	Root bend	0.085	2.7	3.3	83.49	0.001
4-TCT	Face bend	2.68	4.2	4.7	83.49	0.032
	Root bend	1.57	0.4	1.6	83.49	0.019
5-TST	Face bend	1.77	0.8	1.4	83.49	0.021
	Root bend	0.098	2.9	3.6	83.49	0.005
6-TST	Face bend	1.365	0.8	1.0	83.49	0.016
	Root bend	0.565	1.4	1.4	83.49	0.007
7-TST	Face bend	1.104	1.1	1.5	83.49	0.011
	Root bend	1.265	1.3	1.7	83.49	0.015
8-TST	Face bend	0.825	2.4	2.6	83.49	0.01
	Root bend	1.145	1.2	2.1	83.49	0.014
9-SS	Face bend	0.021	0.12	2.1	83.49	0.014
	Root bend	0.165	0.35	2.6	83.49	0.005
10-SS	Face bend	1.245	0.8	2.8	83.49	0.015
	Root bend	1.43	55.6	60.2	83.49	0.017
11-SS	Face bend	1.245	0.6	1.4	83.49	0.015
	Root bend	1.165	0.7	0.9	83.49	0.014
12-SS	Face bend	1.12	0.3	2.9	83.49	0.013
	Root bend	1.715	1.9	7.7	83.49	0.021
13-SS	Face bend	1.475	1.1	2.1	83.49	0.018
	Root bend	2.055	1.8	2.2	83.49	0.025
14-SS	Face bend	1.3	0.9	1.2	83.49	0.016
	Root bend	1.445	0.6	1.1	83.49	0.017
15-SS	Face bend	0.021	0.1	2.4	83.49	0.012
	Root bend	0.165	0.4	3.0	83.49	0.002

Table 4. Impact strength for experimental combinations

Joint No	Absorbed Energy in Joules	Elongation on 50 mm G.L. (%)
1-TCT	3.3	2.0
2-TCT	2.7	2.0
3-TCT	1.8	1.2
4-TCT	2.67	2.0
5-TST	2.4	1.8
6-TST	2.1	1.6
7-TST	1.8	1.3
8-TST	2.7	1.9
9-SS	2.2	1.7
10-SS	2.7	2.0
11-SS	2.0	1.4
12-SS	2.0	1.4
13-SS	2.7	2.0
14-SS	2.7	1.9
15-SS	2.2	1.7

Fig. 6 (a) Typical bending specimens for base alloys (b) typical bend tested specimens for welds

IV. CONCLUSION

This research reveals that there are severe defects in the joints fabricated at a welding speed of 110 mm/min and rotational speed of 1000rpm in which the two materials are not mixed properly in the stirred zone.

The taper cylindrical threaded tool produces good bending and impact strength compared to other tools for this investigation in withstands high ultimate load. The Axial load 12kN is not sufficient for the two materials to mixed in the stirred zone; finally the tunnel defect takes place in the root area of all the joints leads to lesser strength. The suggested axial load is 20kN for the shoulder tool to forge the materials throughout the plate thickness to avoid the tunnel defect.

The tilt angle 0º also a factor for getting lesser strength and the suggested tilt angle should be 1 – 2° for the good ploughing action to bring the stirred materials from the front to back portion of the tool to fill the space created with the advancement of tool in welding direction for good weld consolidation.

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