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MORPHOLOGICAL AND STRUCTURAL STUDY OF FRICTION STIR WELDED THIN AA6061-T6 SHEETS

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ABSTRACT

Friction stir welding is performed on 2mm thick aluminum AA6061-T6 plates. The tool designed was of 10mm shoulder diameter and 1.7mm pin length. The tool rotation speeds were 900 rpm, 1120 rpm, 1400 rpm and 1800 rpm at a constant traverse speed of 125 mm/min. At all these tool rotation speeds defect free welds are successfully obtained. The results suggest at higher rpm, the welds exhibit very smooth surface morphologies. The grain size in the stir zone (SZ) is smaller than that in the base metal due to grain refinement. The hardness value at the weld zone is found less compared to base metal since the alloy is a heat treatable one as expected. The hardness can be regained to a good extend using suitable heat treatments. The hardness profile showed a substantial reduction in hardness in the heat affected zone (HAZ) especially in advancing side due to grain coarsening. Tensile test is done and the results show low tensile strength in weld metal compared to a base metal. Tensile strength of weld found increasing, according to an increase in the percentage of the first mode metal transfer.

KEYWORDS: Friction Stir Welding, Heat Affected Zone, Macro Structure, Micro Structure, Mode Metal Transfer, Onion Ring, Weldability

INTRODUCTION

Aluminum is the most difficult alloy to weld. Aluminum oxide should be cleaned from the surface prior to welding. Aluminum is often chosen as a structural material for applications in which weight savings are important. Aluminum comes in heat treatable and non heat treatable alloys. Very often, the designer will choose the very strongest alloy available. This is a poor design practice for several reasons. First, the critical design limitation for many structures often is deflection, not strength. In such cases, the modulus of elasticity, not the tensile properties, will govern the design. The modulus of most aluminum alloys, weak and strong alike, is approximately the same (one-third the modulus of elasticity of steel), so no benefit accrues from using the strongest alloy. Second, and most importantly, many of the strongest aluminum alloys are not weldable using conventional techniques. Heat treatable aluminum alloys get their strength from a process called ageing. Significant decrease in tensile strength can occurs when welding aluminum due to over ageing.

Weldability of an alloy, is usually referring to the alloy's ability to be welded, without hot cracking. Alloys that are extremely susceptible to hot cracking are not considered appropriate for structural (load-carrying) applications, and are generally put in the non-weldable category. Hot cracking in aluminum alloys is primarily due to the chemistry of the alloy and the weld bead. For virtually every alloying addition, the cracking sensitivity varies. In some cases, such as that of AA6061, which is very crack-sensitive if welded without filler material, the weld cracking sensitivity can be reduced to acceptable levels with the addition of a high silicon or high magnesium filler metal. The additional silicon or magnesium pushes the solidifying weld metal below the cracking sensitivity level. In other alloys, such as AA7075, it is not possible to design a weld filler alloy that results in a crack-resistant chemistry. These are considered to be non-weldable.

EXPERIMENTAL INVESTIGATION

Plates of 6061-T6 aluminum of 2mm thickness are welded using friction stir welding (FSW). Each plate is about 100 x 35 x 2mm dimensions. The chemical composition of the material is given in table 1. Welding is done in the closed square butt joint configuration. The FSW welding has been done with a modified milling machine.

Table 1: Chemical Composition of 6061-T6

Al	Mg	Si	Fe	Cu	Cr	Mn	Ti	Zn
98.05	0.708	0.432	0.497	0.0164	0.148	0.0971	0.0495	0.0042

Tension test is conducted on welded samples of 6061-T6 aluminum alloy. The dimensions of dog bone shaped tensile test samples as shown in Figure 1.

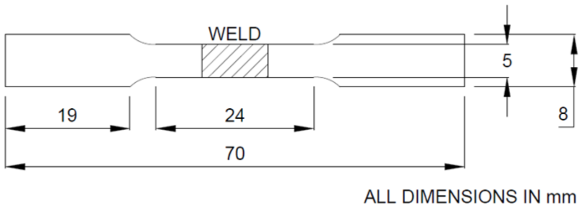

Figure 1: Dimensions of Tension Test Sample

RESULTS AND DISCUSIONS

The experiments are carried out on a modified milling machine for FSW. AA6061-T6 plates are welded with selected welding parameters. The welding parameters are as shown in table 2. In all four welding speed, tried good quality welds achieved with good surface morphologies

Table 2: Parameters Used for FSW

Tool Size					Welding Parameters	
Shoulder Diameter (mm)	Tool Pin Profile	Pin Diameter (mm)	Pin Length (mm)	Tool Tilt Angle (^{0})	Rotation Speed (rpm)	Welding Speed (mm/min)
10	cylindrical	4	1.7	0	900-1800	125

MACRO AND MICROSTRUCTURES

Defects such as voids, cracks and unbonded zones are not observed in and near the SZ, showing that defect-free welds are successfully obtained at all tool rotation speeds. The area of two modes of metal transfer is clearly visible in all rotating speeds. The onion ring structure is formed in the tool rotation speeds ranging from 900 to 1800 RPM. In addition, the increase of the tool rotation speed leads to the increase in the region of the onion ring structure.

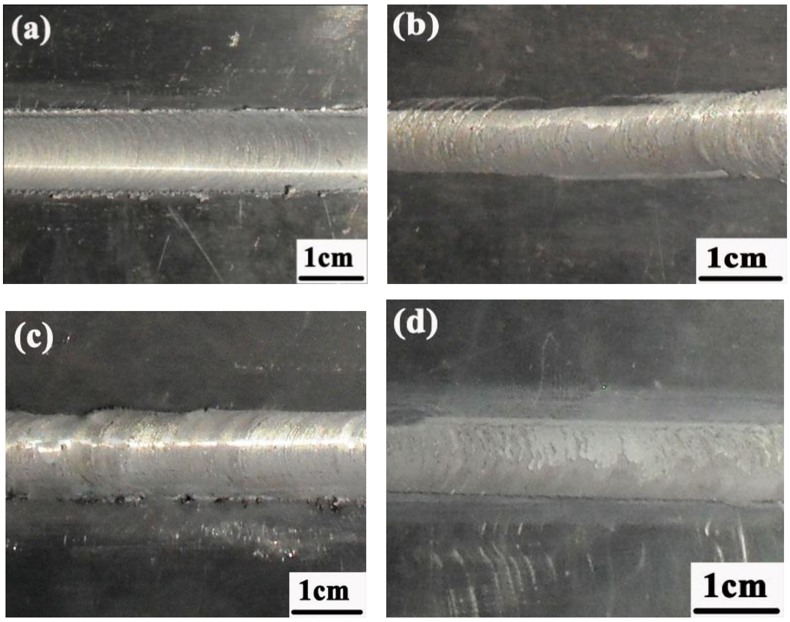

Figure 2: Welded Samples at (a)900 rpm, (b) 1120 rpm, (c) 1400 rpm and (d) 1800 rpm

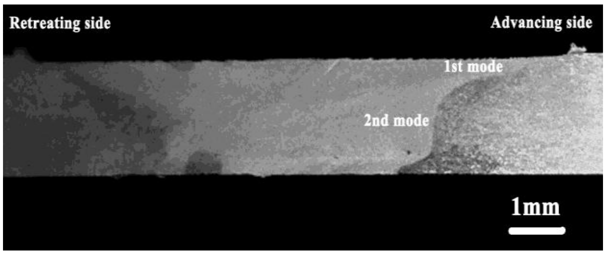

Figure 3: Macro Structure at 900 rpm

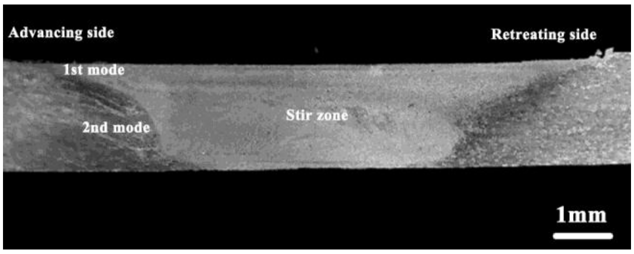

Figure 4: Macro Structure at 1120 rpm

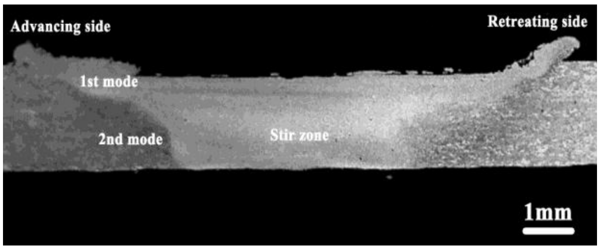

Figure 5: Macro Structure at 1400 rpm

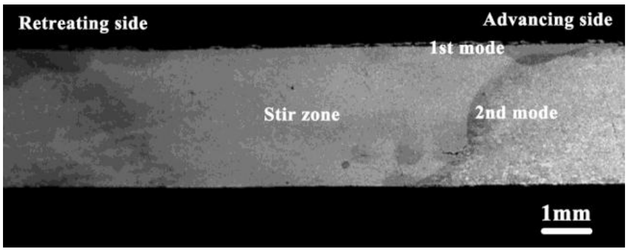

Figure 6: Macro Structure at 1800 rpm

The optical micrographs of the stir zone (SZ) and the modes transition regions on the cross-sections perpendicular to the tool traverse direction of the plates friction-stir-welded at tool rotation speeds of 900, 1120, 1400 and 1800 rpm are shown in figure 7. The SZ is composed of smaller and equiaxed grains. This result suggests that the SZ is severely plastically deformed by the mechanical stirring action of the rotating pin during the FSW process, and then grain refinement occurs as a consequence of dynamic recrystallization.

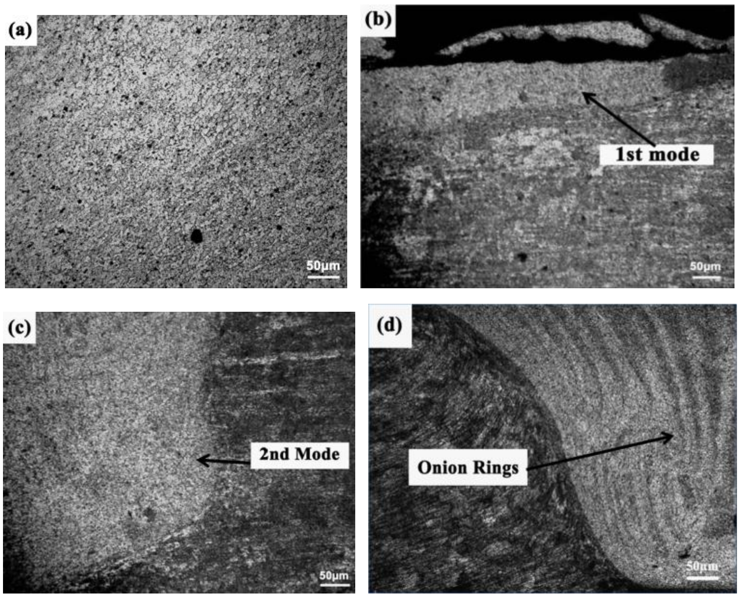

Figure 7: Micro Structure (a) Weld Stir Zone (b) 1st Mode Area (c) 2nd Mode Area and (d) Onion Rings

TENSION TEST

Tension test is conducted on samples. A sample of the broken tensile test specimen is shown in Figure 8. Two samples each tested and an average value of ultimate tensile strength is calculated for each weld. Test samples were broken in welds, suggesting a lowering of tensile strength of the heat treatable aluminum alloy. All tensile samples were broken in advancing side of the weld. The average tensile strength obtained for each rotational speed, is shown in table 3 and is plotted in Figure 9. The ultimate tensile strength is found 300MPa in base metal showing a reduction of 47% of tensile strength for the welds.

Figure 8: A Broken Tensile Sample

Table 3: Average Tensile Strength Obtained for Each rpm

Speed (rpm)	Strength (MPa)
900	161.75
1120	166.51
1400	175.69
1800	158.86

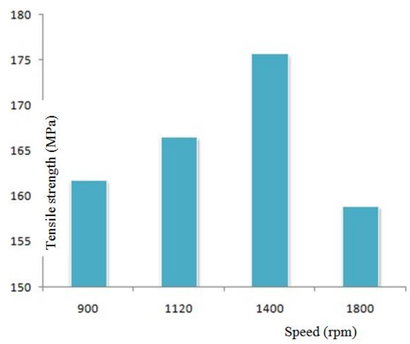

Figure 9: Tensile Strength and Speed

CALCULATION OF FIRST MODE AREA

Attempts have been made to determine the amount of metal transferred by the first mode during friction stir welding and to establish a correlation between the first mode of metal transfer and the tensile strength of cast A6061-T6 aluminum alloys. A relationship between the rotational speed and the percentage of first mode metal transfer also found as plotted in Figure 11. The ultimate tensile strength increases with first mode metal transfer as shown in Figure 12. This enhancement in tensile properties is due to the grain refinement.

The percentage of first mode of metal transfer was computed using the following relation:

$$\%\text{age of First Mode} = \frac{\textit{Cross sectionall area of metal transferred in first mode}}{\textit{Total cross sectional area of weld nugget}}$$

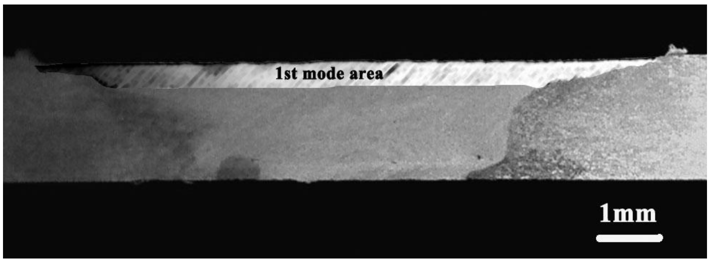

Figure 10: Measured First Mode Area

As shown in Figure 11 percentages of 1st mode transfer is found to increase up to an optimum value and then it is decreasing. In this work maximum percentage of metal transfer was found approximately 38% at tool rotational speed of 1400 rpm. It is found that the tensile strength increases almost uniformly showing a straight line behavior with percentage of 1st mode as shown in Figure 12.

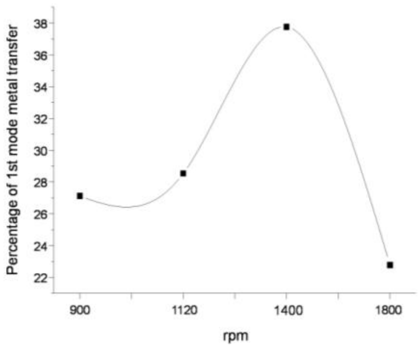

Figure 11: Percentage of 1st Mode and rpm

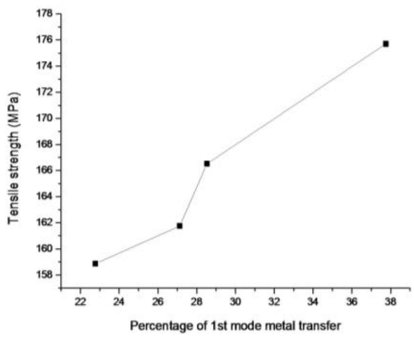

Figure 12: Tensile Strength and Percentage of 1st Mode Transfer

CONCLUSIONS

Friction stir welding of thin plates are known as difficult, due to practical difficulties in preparation of the tool. In this work friction stir welding of 2 mm A6061-T6 aluminum alloy, is done with tool rotational speeds of 900, 1140, 1400 and 1800 rpm. Macro and microstructures were analyzed, for the purpose of studying the modes of metal transfer. Tensile test was conducted to compare the tensile strength of welds, with that of base metal. The effect of percentage of 1st mode of metal transfer of tensile properties also scrutinized. Good surface morphologies were observed for the achieved welds at all tool rotational speeds used. Macro structural studies reveal the presence of two modes of metal transfer, that exist even at thin sheets welding, using friction stir welding. At stir zone fine microstructure due to grain refinement is observed. There was a huge reduction in hardness observed, across the weld cross section, especially at advancing side of the weld due to the coarsening of grains there, during dynamic recrystallization. At welds, the tensile strength was founded lesser than base metal. Tensile strength reduced up to 47%, for the weldment welded at 1800 rpm. Maximum average tensile strength obtained was 175.7 MPa, which is only about 59% of base metal tensile strength. Percentage of 1st mode metal transfer was found maximum 37.75%, for weldment welded at 1400 rpm and minimum 22.78% at 1800 rpm. Percentage of 1st mode metal transfer was found to increase with tool rotational speed, up to an optimum value of rpm and then decreases. Tensile strength of weld found increasing, as the percentage of 1st mode metal transfer increases irrespective of tool rotational speed. This relationship has found almost linear in characteristics.

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