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Evolution of Microstructure and Hardness of Aluminium 6061 after Friction Stir Welding

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Abstract

The effects of friction stir welding (FSW) on the microstructure and hardness of rolled pure aluminium 6061 were investigated. The weld was obtained by varying its tilt angle (2°) and Pin diameter (6mm). Tensile strength & % Elongation was carried out to evaluate the strength of the weld. Optical microscope study was carried out to study the uniform stirring of materials. The stir zone (SZ) contains fine, equiaxed and fully recrystallized grains. Thermomechanically- affected zone (TMAZ), heat-affected zone (HAZ), and base material (BM) were different. Hardness test indicated that the minimum and maximum hardness values were obtained in the HAZ and BM, respectively.

Keywords: FSW; Aluminium alloy, Mechanical properties, Microstructures, SEM

INTRODUCTION

FSW is becoming more popular for joining a wide range of aluminium alloys for numerous applications. One advantage of FSW is that there is far lower heat input during the process compared with conventional welding methods such as TIG or MIG. Therefore, this solid-state process results in to minimal microstructural changes and better hardness and tensile tests than conventional welding [1-3]. The FSW process generates three distinct microstructural zones: the nugget zone (NZ), the thermomechanically affected zone (TMAZ) and the heat-affected zone (HAZ) [4]. The HAZ is only affected by heat, without plastic deformation. The TMAZ adjacent to the nugget is plastically deformed and heated. The nugget is affected by the highest temperature and the highest plastic deformation, which generally consists of fine equixed grains due to the fully dynamic recrystallization.

A relationship between microstructure and microhardness of each FSW weld zone has been discovered [5]. Changes in microharness along the FSW joint are directly related to the precipitation state.

EXPERIMENTAL DETAILS

AA 6061 (0.4 % Si, 0.7% Fe, 0.4% Cu, 0.15% Mn, 1.2% Mg, .35% Cr, 0.25% Zn, 0.15% Ti balance Al) plates of 6mm thick were friction stir welded vertical to the rolling direction with a travel speed, a rotational speed and a shoulder diameter of 20mm/min, 1000 rpm and 25mm.

The friction stir pin had a diameter of 4mm height of 4.8mm. A simultaneous rotation and translation motion of the FSW tool generates the formation of an symmetric weld [6].

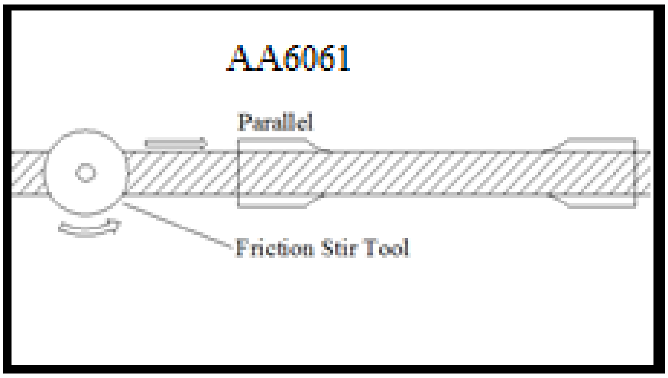


Fig 1 Schematic of the locations from where tensile test specimens were cut from (P-AA6061 (Longitudinal))

Welded cross-sections were ground, polished, and etched with Beaker’s reagent for optical metallography. Instrumental (digital) Vickers micro hardness measurements were also made throughout the weld zone and into the initial aluminium alloy plate using a 50gf load. Tensile specimens were machined from NZ in parallel (longitudinal) direction from the weld. The tensile properties of the joints were evaluated using three tensile specimens cut from the same joint.

3. RESULTS AND DISCUSSIONS

3.1 Mechanical properties

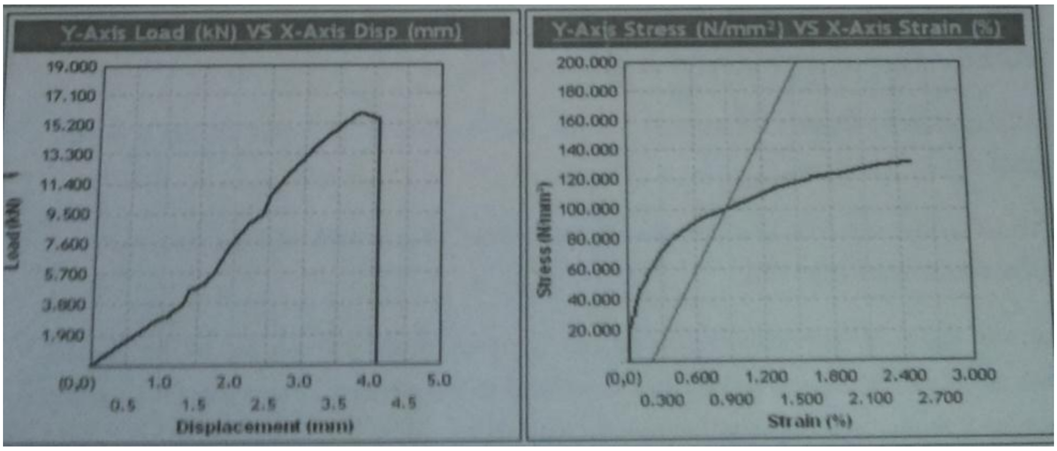


Fig-3 Tensile properties of AA6061-AA6061

As shown in fig 3 the elongation, yield strength, and tensile strength of the BM AA6061 were 2.70%, 136.77 MPa, and 102.21 MPa, respectively. By comparison, the two FSW specimens showed a significant decrease in both tensile and yield strength. Fig 3 also shows that the ductility for tensile specimen P-AA6061 significantly increased. Fig 1, the tensile specimen P-AA6061 contained only recrystallized grains from the NZ. From the hardness results, we know that the hardness values of the NZ were lower than that of the BM, possibly explaining why the longitudinal tensile specimen P-AA6061 exhibited both tensile and yield strength values. When a tensile load was applied to the joint, failure occurred in the weakest regions of the joint [7], which is the HAZ in this work.

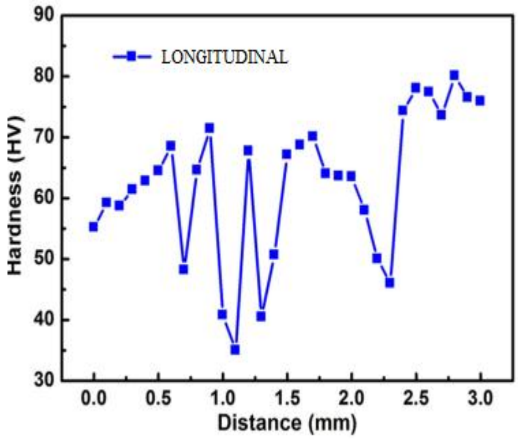


Fig 4 Microharness distribution across the top surface of FSW AA6061-AA6061 measured with a 2mm step

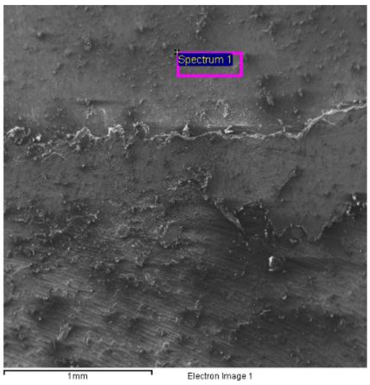
Fig 4 shows the typical microhardness distribution across the top surface of FSW AA 6061-AA6061. The hardness curve is a symmetrical with respect to the weld centreline because the plastic flow field in the two sides of the weld centre is not uniform [8]. The larger distorted grains and distortion energy causes the strain-hardness to increase, resulting in the symmetrical microhardness distribution. The minimum hardness of 85.02 HV was obtained in the HAZ region. The maximum value 106.34 HV was present in the BM. The hardness of the TMAZ was higher than that of the NZ.

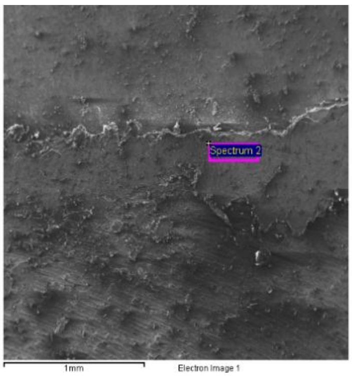
3.2 Microstructure:

The microstructure of the different regions of the welded similar material is shown in fig . The NZ consists of fine equixed grains due to dynamic recrystallization. The grains in NZ are much smaller than those in other regions. The average grain size in the four zones in follows the order of BM>HAZ>TMAZ>NZ. In the TMAZ which is adjacent to the NZ, the strain and the temperature were lower than in the NZ and the effect of welding on the microstructure was correspondingly smaller. Unlike NZ, the microstructure was recognizably that of the parent material, although significantly deformed and rotated. The grain size of the HAZ was similar to that of the BM. The HAZ was common to all welding processes subjected to a thermal cycle, but it was not deformed during welding.

3.3 SEM With EDX analysis:

Elemental analysis of the macro regions in weld zone was performed using a scanning electron microscope (SEM) equipped with an EDX system. This analysis was conducted to gauge the distribution of alloying elements in the FSW zone. SEM image was analyzed at a magnification of 50X, 250X, 500X, 1.50KX





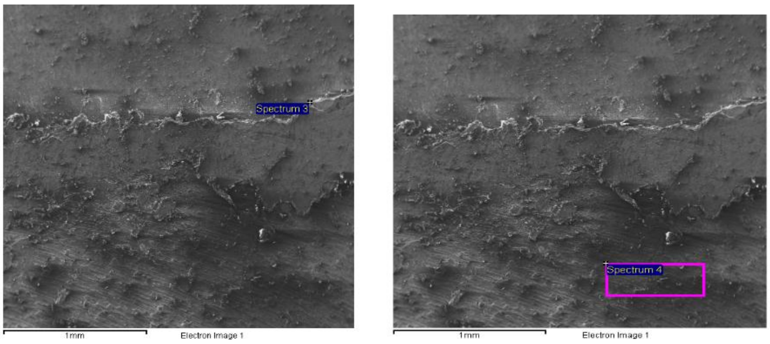


Fig 8 SEM images of FSW AA6061-AA6061 spectrum-1- HAZ, Spectrum-2 – TMAZ, Spectrum-3-NZ, Spectrum-4-BM

Table 1 EDAX quantification results of four points in fig

Element [at. %]	C	O	Al	Si	Cu
Spectrum 1(HAZ)	40.88	10.03	49.09	-----	-----
Spectrum 2 (TMAZ)	32.28	6.14	60.04	1.54	-----
Spectrum 3(NZ)	27.21	4.42	64.28	-----	4.09
Spectrum 4 (BM)	33.76	8.66	57.58	------	-----

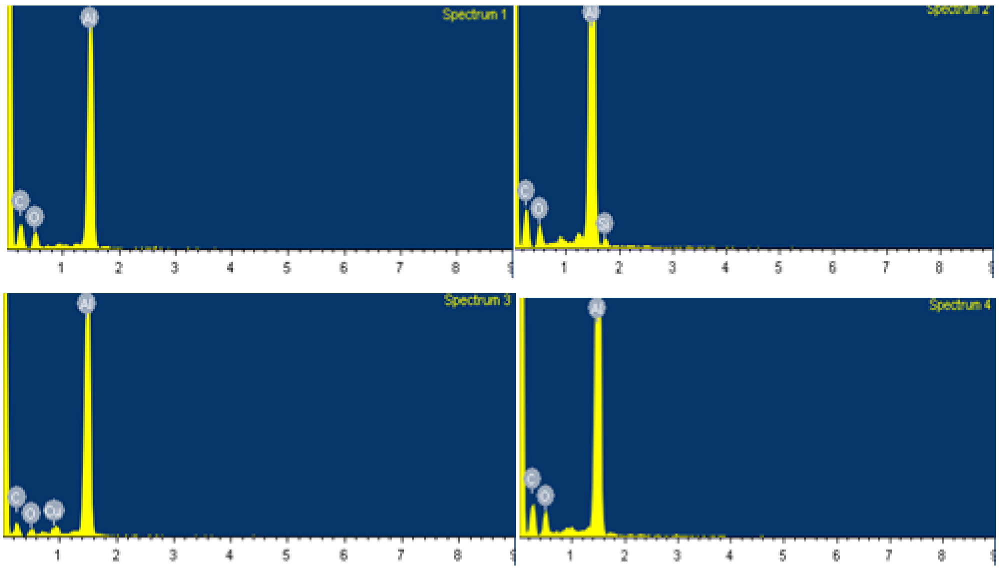


Fig 5 EDAX analysis of FSW AA6061-AA6061 spectrum-1- HAZ, Spectrum-2 – TMAZ, Spectrum-3-NZ, Spectrum-4-BM

The EDAX analysis depicted in Table 1 revealed that high contents of oxygen and aluminium are present.

4. CONCLUSION:

An approach of the microstructure, mechanical properties of FSW AA6061-AA6061 aluminium alloys had been made. The order of average grain size in different weld zones was as follows: BM> HAZ> TMAZ> NZ. The minimum hardness of 80.2 HV was obtained in the HAZ region, and the max value of 106.32 HV was present in the BM. The tensile and yield strengths of the weld zones were less than that of the BM tensile specimens. In to the properties of the BM, the ductility increased in the longitudinal tensile test specimens (that consist of the NZ).Fracture occurred in the HAZ region, which had the lowest hardness of all of the weld zones. The EDAX analysis depicted in Table 1 revealed that high contents of oxygen and aluminium are present.

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