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Experimental Analysis of Friction Stir Processing of TIG Welded Aluminium Alloy 6061

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Abstract

Welding of aluminium poses a great challenge to get a sound proof joint as many problems are encountered during the welding. In view of above fact welding of 6 mm plate of 6061 aluminium alloy , it was decided to weld the 6061 aluminium alloy with different welding processes viz. Gas Tungsten arc Welding (GTAW) & Friction Stir Processing (FSP). This present work aims to demonstrate the TIG welded Friction Stir Processing ability and the emphasis is placed on the relations of the tensile properties and hardness. To improve welding quality of TIG welded Aluminium alloy (Al-6061 T6) with the Friction Stir Processing. Tensile strength and hardness value of TIG welded joint and TIG welded plus Friction Stir Processed joint is investigated. The welded specimens were subjected to tensile testing, hardness testing and microstructure study. Tensile results obtained from this study show that the average UTS value is 299 MPa for base metal, 85 MPa for the TIG and 125 MPa for TIG + FSP, hence showing 48% increase from the TIG welded joint. Hardness value of base metal comes out to be 74. The hardness value of TIG + FSP specimen comes out to be 72-74 which is almost similar to that of base metal that is 74 whereas in TIG specimen hardness value is 66-68 and hence there is improvement in the hardness value. Optical microscopic analysis has been done on the weld zone to evaluate the effect of welding parameters on welding quality and microstructure. Microstructure of TIG + FSP joint is very fine equiaxed recrystallized grained which is better than the microstructure of TIG joint which is column and is fineaxed.
Keywords: TIG welding, Friction Stir Processing (FSP), 6061 Aluminium Alloy, Tensile Strength, Microstructure

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I. INTRODUCTION

Aluminium alloys are important for the fabrication of components and structures which require high strength, low weight or electric current carrying capabilities to meet their service requirements. Among all aluminium alloys, AA 6061 alloy plays major role in the aerospace industry in which magnesium and silicon are the principal alloying elements. It is widely used in the aerospace applications because it has good formability, weldability, machinabilty, corrosion resistance and good strength compared to other aluminium alloys. When using the conventional arc welding techniques, long butt or lap joints between AA 6061 and other aluminium alloys are particularly difficult to make without distortion because of high thermal conductivity and special welding procedures and high levels of welder skill are generally required.

TIG is an arc welding process wherein coalescence is produced by heating the work piece with an electrical arc struck between a tungsten electrode and the job. The electrical discharge generates a plasma arc between the electrode tip and the work piece to be welded. It is an arc welding process wherein coalescence is produced by heating the job with an electrical arc struck between a tungsten electrode and the job. The arc is normally initialized by a power source with a high frequency generator. This produces a small spark that provides the initial conducting path through the air for the low voltage welding current.

The arc generates high-temperature of approximately 6100 C and melts the surface of base metal to form a molten pool. A welding gas (argon, helium, nitrogen etc) is used to avoid atmospheric contamination of the molten weld pool. The shielding gas displaces the air and avoids the contact of oxygen and the nitrogen with the molten metal or hot tungsten electrode. As the molten metal cools, coalescence occurs and the parts are joined. The resulting weld is smooth and requires minimum finish.

Friction stir processing (FSP) is a solid-state process which means that at any time of the processing the material is in the solid state. In FSP a specially designed rotating cylindrical tool that comprises of a pin and shoulder that have dimensions proportional to the sheet thickness. The pin of the rotating tool is plunged into the sheet material and the shoulder comes into contact with the surface of the sheet, and then traverses in the desired direction. The contact between the rotating tool and the sheet generate heat which softens the material below the melting point of the sheet and with the mechanical stirring caused by the pin, the material within the processed zone undergoes intense plastic deformation yielding a dynamically-recrystallized fine grain microstructure.

II. OBJECTIVES OF RESEARCH

The objectives of this study was:

- To investigate the tensile strength, hardness and microstructure of the TIG welded aluminium alloy AA 6061 and TIG + FSP aluminium alloy AA 6061.
- To improve and investigate the mechanical properties of Friction Stir Processing of TIG welded joint.
- To improve the microstructure of TIG welded aluminium joint (AA-6061 T6) with friction stir processing process.

III. EXPERIMENTAL WORK

A. *Experimentation*

Material used in this study was AA6061 alloy. The AA6061 aluminium alloy was cut into four 300 mm * 80 mm * 6 mm pieces with the help of band-saw and grinding done at the edge to smooth the surface to be joined. After that surfaces are polished with emery paper to remove any kind of external material or dust. The AA6061 base metal plates were prepared for welding. After sample preparation, two base metal plates were fixed in the working table and double sided butt welded joint was formed with ER 4047 filler material and same joint was performed on the other two base metal plates.

After performing the welding, two welded specimens were obtained of dimensions of 320 mm * 300 mm. Out of the two welded specimens one is inspected for the Tensile strength test , for the Vickers hardness test and for the microstructural study and on the other specimen Friction Stir Processing technique is performed for improving the results on TIG welded specimen.

Table – 1
TIG welding process parameters

Parameters	*Range*
Voltage	*20-22 V*
Current	*150 Amps*
Gas flow rate	*10-12 L/min*
Shielding gas	*Argon*
Welding speed	*3mm/sec*
Filler wire	*ER 4047*
Filler wire diameter	*1.6 mm*
TIG Setup	*Manual*

FSP tool is very important and critical element of the process. The tools which was used in this work was made of EN 31 steel and consists of a shoulder and concentric pin. The shoulder diameter of the tool is 20 mm and the pin of the non-consumable tool was a cylindrical circular pin with a diameter of 6mm and length of 5.2 mm.

Table – 2
FSP process parameters

Parameters	*Range*
Rotational speed	*1200 rpm*
Travel speed	*75 mm/min*
Tool type	*Cylindrical pin*
Shoulder diameter	*20 mm*
Pin diameter	*06 mm*
Pin length	*5.2 mm*

B. *Testing*

1) *Tensile Strength Testing:*

Ultimate tensile strength (UTS) often shortened to tensile strength (TS) or ultimate strength and is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. Tensile strength is defined as a stress, which is measured as force per unit area. Maximum tensile strength and toughness was calculated from the stress strains graph plotted during tensile test. In the SI system, the unit is the Pascal (Pa) Newton per square meter (N/m^2).In tensile testing specimen were prepared according to Indian standard IS 1608 and its testing is done on UTM and images of post tensile tesing are shown in fig. 1 , fig. 2 and fig 3

Fig. 1: Tensile specimen of base metal after fracture

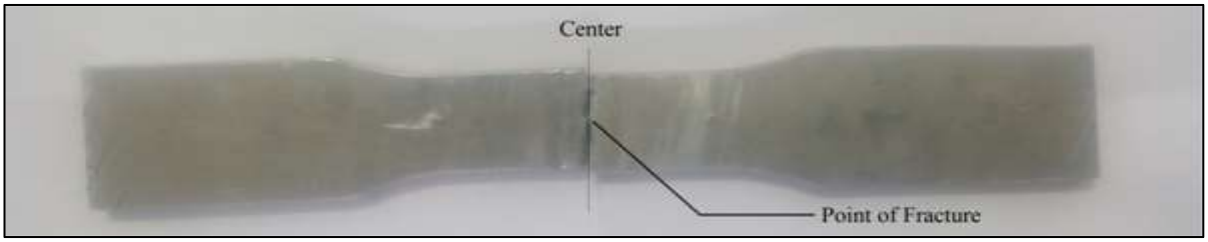

Fig. 2(a)

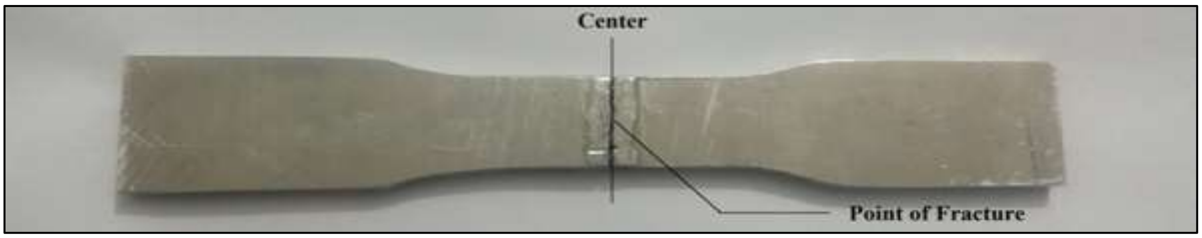

Fig. 2: Tensile specimens of TIG welded joint after fracture

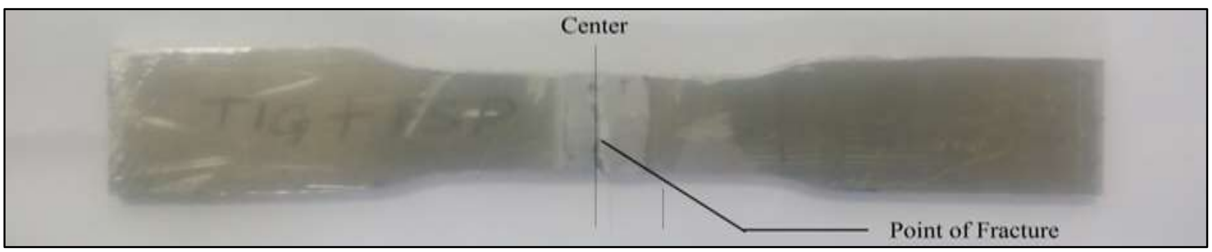

Fig. 3(a)

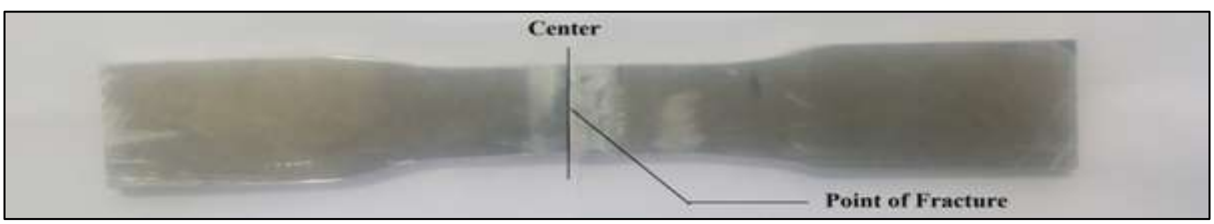

Fig. 3(b)
Fig. 3: Tensile specimens of TIG + FSP joint after fracture

2) *Vickers Hardness Test:*

The Vickers hardness done on welded specimen by indenting them with a on welded specimen by indenting them with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces and subjected to a load of 1 to 100 kgf .

After experimentation data tabulated as per the under given vicker hardness equation. Micro-hardness measurement was done on weld pool and on heat affected zone (HAZ) for each sample. Before micro-hardness measurement cross section of the welded specimen mounted and polished with 220, 600 and 1200 grit size polishing paper sequentially. Micro-hardness was measured with Vickers micro-hardness tester and is performed at CITCO – IDFC testing laboratory.

3) *Microstructure Study:*

When describing the structure of a material, we make a clear distinction between its crystal structure and its microstructure. The term crystal structure is used to describe the average positions of atoms within the unit cell, and is completely specified by lattice type and the fractional coordinates of the atoms. In other words, the crystal structure describes the appearance of the material on an atomic length scale. The term microstructure is used to describe the appearance of the material on the nm-cm length scale.

IV. RESULTS AND DISCUSSION

A. Tensile Test Results

Tensile tests was performed on universal testing machine (Model: UTE -100 make) with maximum load capacity 600 KN at CITCO lab, Chandigarh. Maximum tensile strength and toughness was calculated from the stress strains graph plotted during tensile test.

Fig. 4 shows the tensile strength value for the base metal i.e aluminium alloy AA 6061, the tensile strength valueof the welded joint produced by TIG welding and the tensile strength value of the TIG + FSP welded joint. The tensile strength of the pure aluminium alloy 6061 T6 comes out to be was 299 MPa and the percentage elongation was 23. The tensile strength of TIG welded joint was 85 MPa and the percentage elongation was 1.1 and the tensile strength of TIG+FSP joint was 126 MPa and the percentage elongation was 1.2.

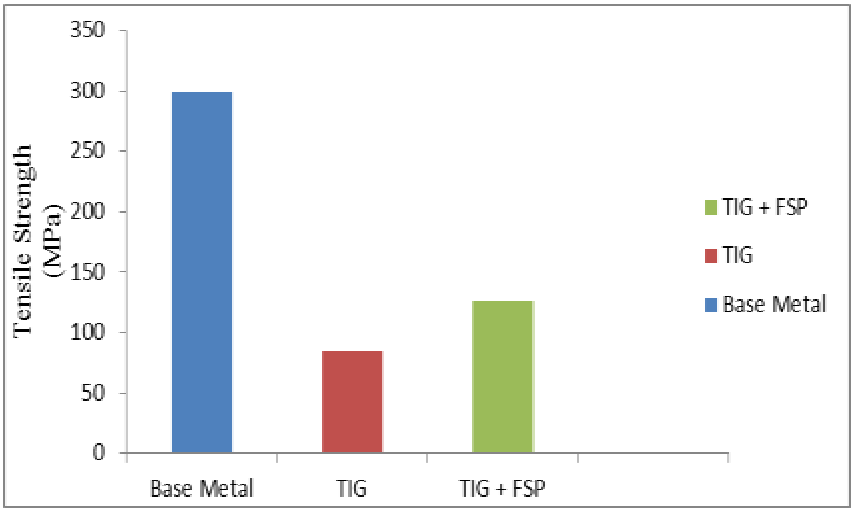

Fig. 4: Tensile Strength Chart of Tensile Specimen

B. Hardness Results

The Vickers hardness done on welded specimen by indenting them with a on welded specimen by indenting them with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces and subjected to a load of 1 to 100 kgf with the Vickers micro-hardness tester and is performed at CITCO – IDFC testing laboratory.

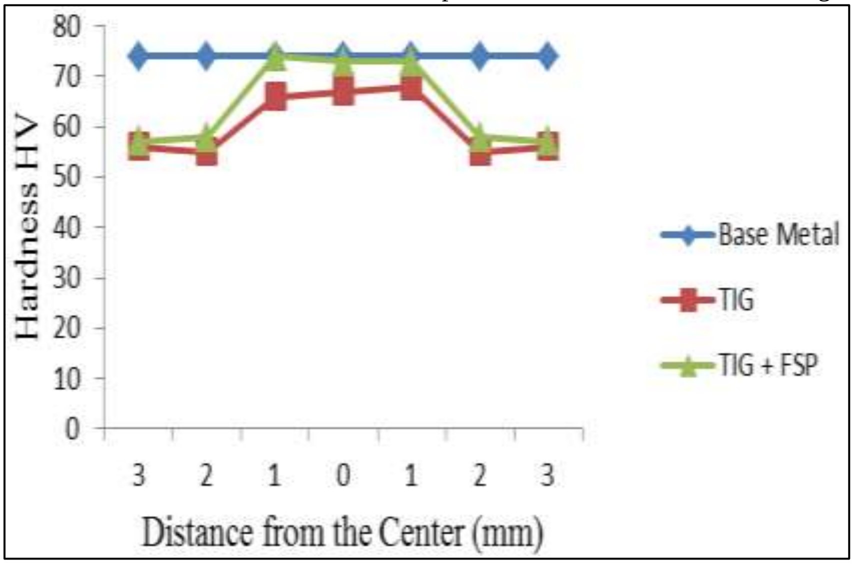

Fig. 5: Hardness value chart of Test Specimen

Fig. 5 shows the hardness value of test specimen from the center to the heat affected zone (HAZ). The hardness value of the base metal comes out to be was 74. The hardness value of TIG welded joint at the weld pool was 66-68 and at the heat affected zone (HAZ) was 55-56 whereas the hardness value of TIG + FSP joint at the weld pool was 72-74 and at the HAZ was 57-58.

C. *Microstructure Study*

Microstructure of Base metal and the microstructure of TIG welded specimen at the cross section of the weld and the microstructure of TIG welded Friction Stir Processed specimen at the cross section of the weld was taken by using an optical microscope at 100x magnification after proper polishing at CITCO – IDFC testing laboratory. Microstructure of base metal (Aluminium Alloy - 6061 T6) , TIG welded specimen and the TIG + FSP specimen are shown in Fig. 6 , Fig. 7 and Fig. 8 respectively.

Fig. 6: Microstructure of Base Metal (AA - 6061)

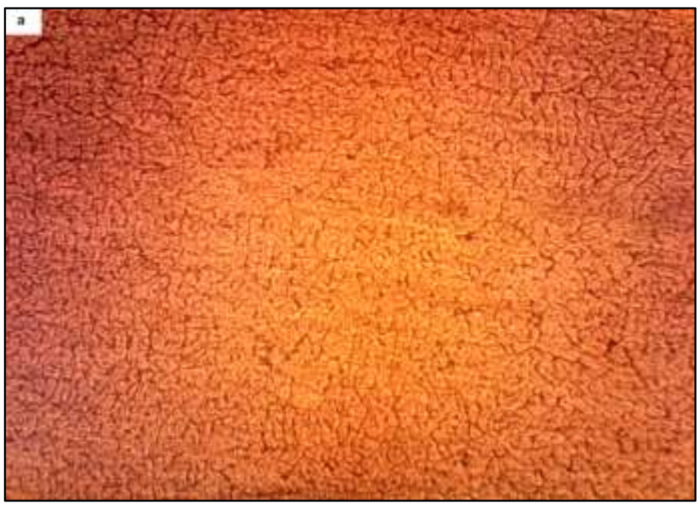

Fig. 7a: Weld pool zone

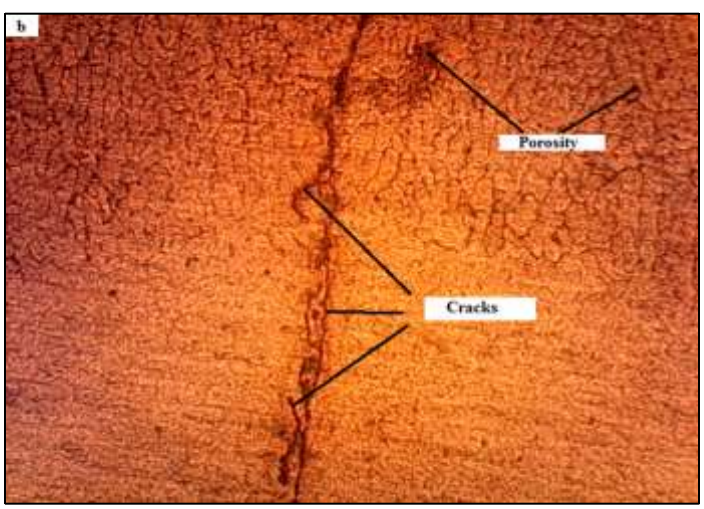

Fig. 7b. HAZ and unaffected zone
Fig. 7: Microstructure of TIG welded joint

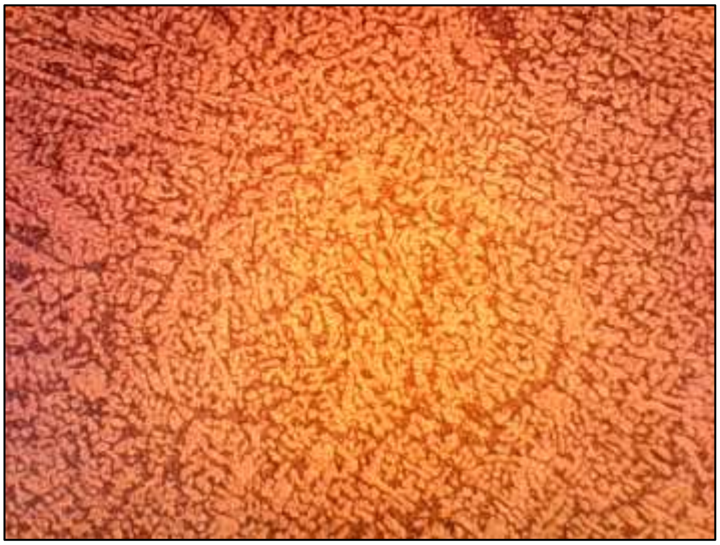

Fig. 8: Microstructure of TIG + FSP joint

Microstructure of the base metal AA 6061 shown in Fig. 6 has an excess of Mg2Si at the solutionizing temperature. Microstructure of the base metal showing insoluble (Fe,Cr)3SiAl12 and excess soluble Mg2Si particles which represents the dark as redistributed by mechanical working. 0.5% hydrofluoric acid.

The optical micrographs of the weld pool and the HAZ and unaffected zone of TIG welded specimen are shown in Fig. 7. It can be observed that the grain structure was column and was fineaxed at the weld pool. A high density of dislocations with network structure observed in many grains and porosity and cracks were observed and because of that the tensile strength comes out was less than that of base metal.

The optical micrograph of the friction stir processed zone is shown in Fig. 8. The structure increasingly coarer and column for TIG + FSP joint. This deformation leads to the formation of very fine equiaxed recrystalized grains with in the friction stir processed zone. Various dislocations with network structure observed in the recrystalized grains. A high density of dislocations with network structure observed in many grains. Hence, the tensile properties of FSW joints is superior as compared to TIG welded joint due to thermo mechanical processing taking place during friction stir processing.

V. Conclusions

Based on the present work of TIG welding of aluminium alloy 6061 T6 and Friction Stir Processing of TIG welded aluminium alloy 6061 T6 the following conclusions have been drawn :

1) Both TIG and Friction Stir Processing (FSP) can be used for welding 6 mm thick plates of aluminium alloy 6061 T6
2) Based on the present results the UTS of the base metal is higher than both the TIG welded joint and TIG + FSP joint
3) UTS of the TIG welded joint is 85 MPa and the UTS of the TIG + FSP joint is 126 MPa , hence showing 48% increase from the TIG welded joint
4) The hardness value of TIG + FSP specimen is almost similar to that of base metal that is 74 whereas in TIG specimen hardness value is 66-68 and hence there is improvement in the hardness value
5) Microstructure of TIG + FSP joint is very fine equiaxed recrystallized grained which is better than the microstructure of TIG joint

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