An experimental investigation of mechanical properties of Al 6106 t6 alloy joined by Friction Stir Welding and TIG welding

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Abstract : FSW is a solid state new joining process that is presently attracting considerable interest. In this process the two pieces of metal are mechanically intermixes at the place of join, then often them so that the metal can be fused using mechanical pressure. Some aluminum alloys can be welded with electrical resistance techniques, TIG, MIG provided that an extensive surface preparation and the oxide formation is controlled. On the contrary, FSW can be used with success to weld most of Al alloys considering that superficial oxide generation is not deterrent for the process and no particular cleaning operations are needed before welding. friction stir welding was mainly developed for aluminum alloys. Al 6101 T6 aluminum alloy has been selected to perform FSW. Al 6101 alloy has been welded with FSW and TIG welding techniques. It has been found that tensile strength and hardness of FSW is more than that of TIG welding. The mechanical properties of both welding specimen has been compared and with base metal strength. Microstructure has also been examined.

Keywords : FSW, TIG, Aluminum alloy

I. INTRODUCTION

Welding is a fabrication process used to join materials, usually metals or thermoplastics, together. During welding, the pieces to be joined (*the workpieces*) are melted at the joining interface and usually a filler material is added to form a pool of molten material (*the weld pool*) that solidifies to become a strong joint. Aluminum alloys are the alloys in which aluminum is a predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc. Processing of aluminum alloys is very difficult. For welding of aluminum alloys, fusion welding and solid state welding processes are used. In this work welding of aluminum alloy by TIG and FSW is done and effect is compared.

II. TIG WELDING

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used. A constant-current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapors known as a plasma. GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys. The process grants the operator greater control over the weld than competing processes such as shielded metal arc welding and gas metal arc welding, allowing for stronger, higher quality welds. However, GTAW is comparatively more complex and difficult to master, and furthermore, it is significantly slower than most other welding techniques. A related process, plasma arc welding, uses a slightly different welding torch to create a more focused welding arc and as a result is often automated.

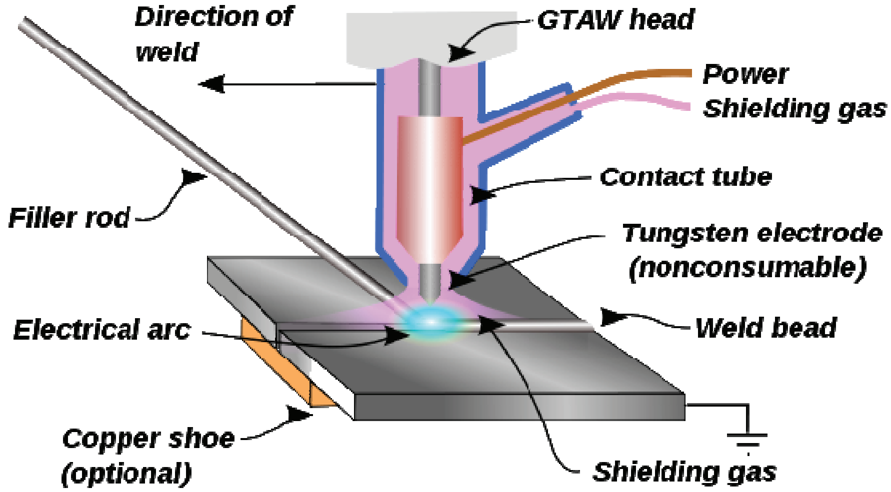


Fig.1 TIG welding process.

Solid state welding - Friction Stir Welding (FSW):
FSW is a solid state new joining process that is presently attracting considerable interest. In this process the two pieces of metal are mechanically intermixes at the place of join, then often them so that the metal can be fused using mechanical pressure. In this welding process, a rotating welding tool is driven into the material at the interface of, for example two adjoining plates, and then translated along the interface. In this process, joining is done with the help of frictional heat generated at the faying surfaces of the two sheets to be joined with the specially designed rotating tool. In the FSW process, a special tool mounted on a rotating probe travels down through the length of the base metal plates in face-to-face contact; the interface between welding tool and the metal to be welded generates the plastically deformed zone through the associated stirring action. At the same time, the thermo-mechanical plasticized zone is produced by friction between the tool shoulder and the top plate surface and by contact of the neighbor material with the tool edges, including plastic deformation.

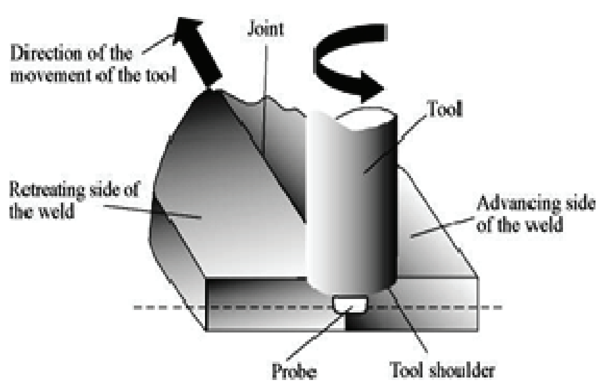


Fig.2 Two discrete metal work pieces butted together, along with the tool (with a probe).

The probe is slightly shorter than the thickness of the work piece and its diameter is typically equal to the work piece thickness. On one side, where the tool rotation is with the direction of the translation of the welding tool one speaks of the advancing side, whereas on the other side, the two motions, rotation and translation counteract and one speaks of the retreating side. Basically, a non consumable tool is used.

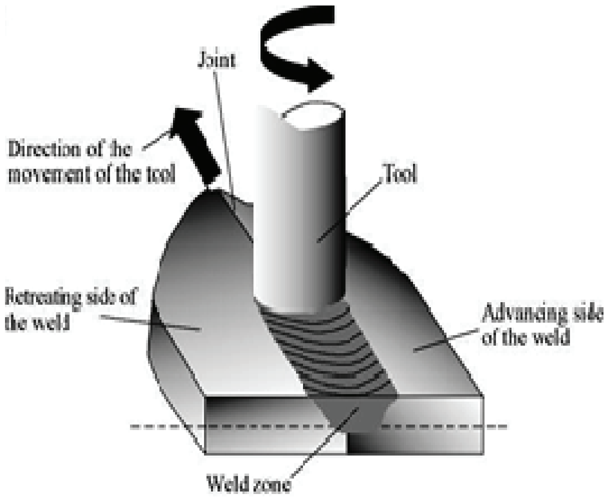


Fig.3 The progress of the tool through the joint, also showing the weld zone

Although the work piece does heat up during friction stir welding, the temperature does not reach the point of the melting. The welded friction stir joint does not have the dendritic structure like conventional fusion-weld joint, cause of degradation of mechanical properties.

III. EXPERIMENTAL WORK

Material '6101' Al alloy was selected with dimensions 3657 mm × 75 mm × 6 mm and the required dimension for FSW was 160 mm × 30 mm × 3 mm. The required specimens were prepared with the help of milling machine.

Fig.4 Prepared Aluminum plate for FSW

Before welding, the 6101 alloys were aged to the T6 temper, i.e. solution treated and artificially aged to the peak strength, the chemical compositions of Al 6101 alloys are presented in Table 1.

Table 1: Chemical composition of 6101 aluminum alloy

Aluminum	B	Cr	Cu	Fe	Mg	Mn	Remainder Each	Remainder Total	Si	Zn
Balance	0.06 max	0.03 max	0.1 max	0.5 max	0.35 - 0.7	0.03 max	0.03 max	0.1 max	0.3 - 0.7	0.1 max

Table 2: Physical properties of 6101 aluminum alloy

Density	2.7 g/cm^3
Melting point	588°C

Table 3:Mechanical properties of 6101 aluminum alloy

Tensile strength	97 MPa
Yield strength	76 MPa
Elastic modulus	70-80 GPa
Poisson's ratio	0.33

Table 4: Thermal properties of 6101 aluminium alloy

Thermal expansion	23 (10^{-6}/ºC)
Thermal conductivity	218 W/mK

IV. TOOL PREPARATION (FOR FSW):

HCHCR (High Carbon High Chromium) steel was selected as the tool material. Friction stir welding has been done on milling machine. The tool was rotated at 1400 rpm and feed was 20mm/min. Four clamps were used to clamp aluminium pieces on milling machine. Welding set up has been shown in figure 5.

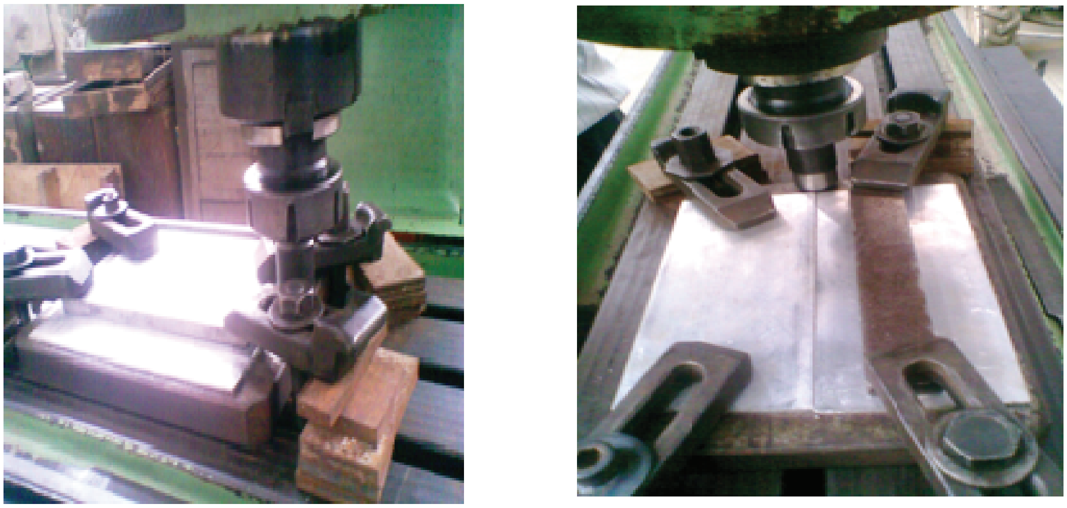


Fig.5 Al 6101 T6 Plates clamped on milling machine

When tool was rotating through joint of two aluminium pieces, then that portion of aluminium was going under plastic region and then finally welding took place.

Fig. 6 Top view of Friction stir welded pieces

Fig. 7 Backside of Friction stir welded pieces

TIG welding Process:

TIG welding was also done on the same aluminium alloy i.e. Al 6101 T6. In this fusion welding good weld bead has been achieved as shown in figure 8. In this welding non consumable tungsten electrode was used. In this welding dimensions of specimen were same as used in FSW.

Fig. 8 TIG welded Al 6101 T6 plate

V. RESULTS AND DISCUSSIONS

Tensile testing was done on Universal tensile testing machine. Three samples of each FSW and TIG welded pieces were prepared with gauge length of 50 mm. Hardness testing of welded samples was done on macro-vicker tester by taking load 500 gm. The weld bead was polished carefully and then etched with solutions of acids or alkalies to better study the study of the macrostructure reveals discontinuities in the metal (cavities, porosity, gas bubbles, stratification, and fissures), distribution of impurities and nonmetallic inclusions, shape and distribution of crystallites (grains) and the structural features of individual grains of the metal in various parts of weld bead. It will help in better conclusions regarding quality of initial materials and the correctness of the conduct of casting, pressure working, and welding processes For microstructure development weld bead is cut from the sample and mounted with the help of epoxy powder. Mounted samples polished manually on emery paper of different grades (80, 320, 400,600, 800, 1000) with kerosene oil. After that mounted samples were cloth polished with diamond paste. To developed microstructure samples were etched with the help of Killer's reagent for 1 mint.

Mechanical properties of weld and base metal of Al 6101 T6 alloy welded by TIG and FSW welding is given in the table below. The HAZ formed on the both the side of the weld, i.e. advancing and retreating side of weld. The reason behind formation of the heat affected zone is temperature difference across the weld. Since the alloy plate was at room temperature before welding. When the welding was done by the rotation of tool, there was substantial increase in temperature due to the friction generated between the tool and work piece and due to the plastic deformation of work piece. Hence, grain growth was observed in the HAZ. Heat Affected Zone HAZ has the lowest strength due to significant coarsened precipitates and the development of free precipitates zones

Table 5: Mechanical properties of FSW and TIG welded samples

Material (Al 6101)	Yield Strength MPa	Tensile Strength, MPa	Elongation, " [%]	Micro Hardness HV-500gm
Base	174	200	9.4	75
Weld (FSW)	69	121	3.23	69
Weld (TIG)	49	78	1.82	53

Mechanical Properties:

Figure 9 shows the graph of load-elongation for Friction stir welding and TIG welded sample during uniaxial loading. These graphs are converted into Engg. Stress- Engg. Strain curves for the calculation of ultimate tensile strength and % elongation. All tensile samples has broken from base metal. Friction stir welded and TIG welded joint both showing less values of % elongation. The welded specimens have lower mechanical properties compared to the base materials. In 6101-T6 alloy , the yield and ultimate tensile strengths decreased by approximately 59% and 40%, respectively, from base material. The corresponding decrease for TIG welded specimen was found to be 70% and 60%. Also elongation was lower than the base material. The welded materials have lower yield stress, tensile strength and hardness compared to the base materials. For all tested welds, fracture surfaces revealed typical ductile rupture.

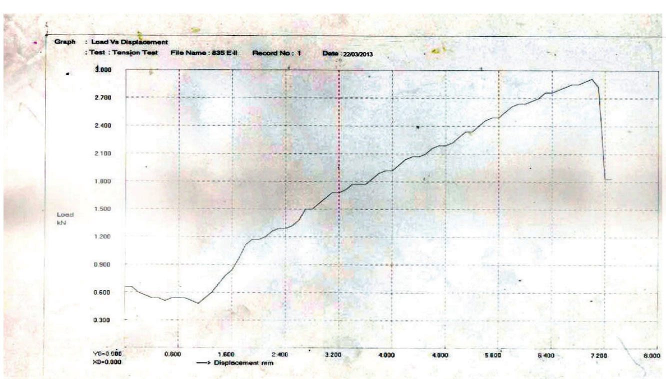


Fig 9 (a)

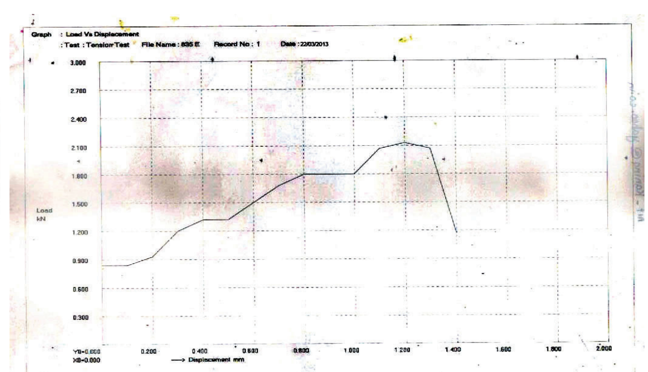
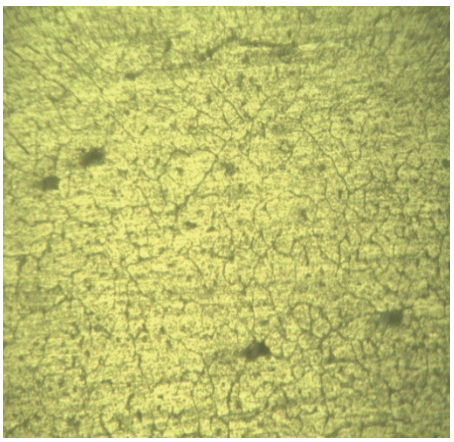


Fig 9 (b)

Fig.9(a): Graph showing variation of load with displacement during tensile testing of FSW welded pieces (b) Graph showing variation of load with displacement during tensile testing of TIG welded piece.

Microstructure:
To correlate the microstructural characteristics with the mechanical properties of the welds, tensile tests and hardness measurements were performed. Tensile samples were prepared from base and welded material. Tensile samples were excised from the welded material in such a way that the tensile axis was perpendicular to the weld seam. With this specimen orientation, the weld is centered along the tensile specimen, and as such, the load is applied transverse to the weld direction and across all microstructural regions associated with the welding process, i.e. the weld nugget, the heat affected zone (HAZ) and the thermomechanically affected zone (TMAZ) distinctive to FSW. The Vickers hardness profile of the welds was measured on the cross-section perpendicular to the welding direction.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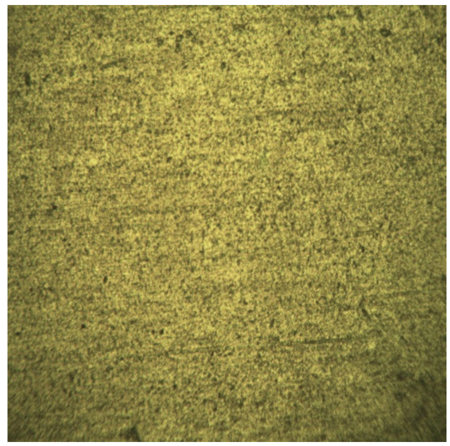
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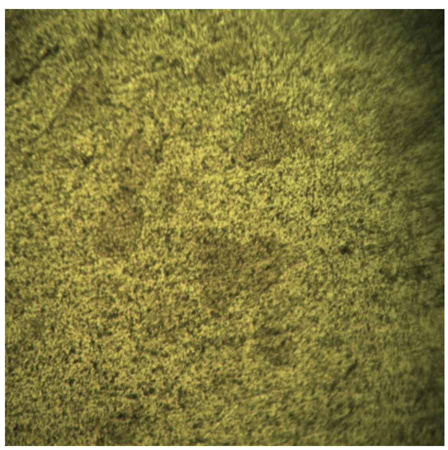
(c)

Fig. 10: Developed Microstructure of (a) TIG welding (b) FSW welding (c) Base metal

In case of TIG welding the structure consists of intermediate network of aluminum silicon eutectic in weld bead while in case of FSW and base metal the structure consists of silicon eutectic in aluminum matrix.

VI. CONCLUSIONS

1. Friction stir and TIG welding of Al 6101 T6 alloy has been done successfully.

2. Tensile strength of FSW is more than that of TIG welding of Al 6101 T6 aluminium alloy. Friction stir welded and TIG welded joint both showing less values of % elongation. The welded specimens have lower mechanical properties compared to the base materials. In 6101-T6 alloy , the yield and ultimate tensile strengths decreased by approximately 59% and 40%, respectively, from base material. The corresponding decrease for TIG welded specimen was found to be 70% and 60%. Also elongation was lower than the base material. The welded materials have lower yield stress, tensile strength and hardness compared to the base materials.

3. Hardness of FSW is also more than that of TIG welding of Al 6101 T6 aluminium alloy.

4. For all tested welds, fracture surfaces revealed typical ductile rupture.

5. Microstructure of both welded specimen as well as base metal had been examined. In case of TIG welding the structure consists of intermediate network of aluminum silicon eutectic in weld bead while in case of FSW and base metal the structure consists of silicon eutectic in aluminum matrix.

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