INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 3, Issue 5)
Available online at www.ijariit.com

A Comparative Research b/w Friction Stir Welding Processes and TIG Welding Processes for [A6061] Aluminium Alloy

Ankur Gill
Assistant Professor
Mechanical Engineering
Swami Vivekanand Institute of Engineering & Technology, Chandigarh
ankurgill6@gmail.com

Bikramjeet Singh
Research Scholar
Mechanical Engineering
Bhai Gurdas Institute of Engineering & Technology, Sangrur, Punjab
bikrambalian@gmail.com

Gurpreet Singh Chahal
Assistant Municipal Engineer, MCD, Malerkotla, Punjab
preetchahal26@gmail.com

***Abstract**: An experimental investigation has been carried out on microstructure and tensile properties of weld b of aluminium alloy. Two different welding processes have been considered: a conventional tungsten inert gas (TIG) process and an innovative solid state welding process known as friction stir welding (FSW) process. In this study, it has been found that heat affected zone of FSW is narrower than TIG welding and mechanical properties like tensile strength etc. are within the comfort zone and are better than TIG welding method. Microstructure results also favour FSW. TIG welding process produces the sound joints but the newly developed method friction stir welding process gives better joints than TIG welding process. The effect of two welding processes on mechanical and metallurgical properties is studied in this research work. Mechanical properties of the welded joints were evaluated and it was found that friction stir welded joints have superior mechanical properties as compared to TIG welded joints. From the micro structure analysis, it was observed that fine and equiaxed grains were observed in the friction stir welded joints and coarse grains were observed in TIG welded joints.*

Keywords: Friction Stir Welding, TIG Welding, Aluminium Alloy, Mechanical, Metallurgical Properties.

I. INTRODUCTION

Aluminium, the second most plentiful metallic element on earth, became an economic competitor in engineering applications as recently as the end of the 19th century. It was to become a metal for its time. The emergence of three important industrial developments would, by demanding material characteristics consistent with the unique qualities of aluminium and its alloys, greatly benefit growth in the production and use of the new metal. When the electrolytic reduction of alumina ($Al_2 O_3$) dissolved in molten cryolite was independently developed by Charles Hall in Ohio and Paul Heroult in France in 1886, the first internal-combustion-engine-powered vehicles were appearing, and aluminium would play a role as an automotive material of increasing engineering value. Systems for designating Aluminium and Aluminium alloys that incorporate the product form (wrought, casting, or foundry ingot), and its respective temper (with the exception of foundry ingots, which have no temper classification) are covered by American National Standards Institute (ANSI) standard H35.1. The Aluminium Association is the registrar under ANSI H35.1 with respect to the designation and composition of aluminium alloys and tempers registered in the United States.

Wrought Aluminium and Aluminium Alloy Designation System

A four-digit numerical designation system is used to identify wrought Aluminium and Aluminium alloys. As shown below, the first digit of the four-digit designation indicates the group: For the 2XXX *through* 7XXX series, the alloy group is determined by the alloying element present in the greatest mean percentage. An exception is the 6XXX series alloys in which the proportions of magnesium and silicon available to form magnesium silicide (Mg_2Si) are predominant. Another exception is made in those cases in which the alloy qualifies as a modification of a previously registered alloy.

If the greatest mean percentage is the same for more than one element, the choice of group is in order of group sequence: copper, manganese, silicon, magnesium, magnesium silicide, zinc, or others.

Table 1.1 Al-Alloy Designation

Al-Alloy Designation	Principal Alloying Element
1xxx	none
2xxx	Cu
3xxx	Mn
4xxx	Si
5xxx	Mg
6xxx	Mg and Si
7xxx	Zn
8xxx	Other

Introduction to FSW Technique

In today`s modern world there are different welding techniques to joint metals. They range from the conventional oxyacetylene torch welding to laser welding. The two types of welding can be divided as fusion welding and pressure welding. The fusion welding process involves bonding of the metal in the molten stage and may need a filler material if required such as a consumable electrode or a spool of wire. Some processes may also need an inert ambience in order to avoid oxidation of the molten metal. A flux material or an inert gas shield in the weld zone protects weld pool to avoid defects. Examples of fusion welding are metal inert gas welding (MIG), tungsten inert gas welding (TIG) and laser welding. There are many disadvantages in the welding techniques where the metal is heated to its melting temperatures and let it solidify to form the joint. The melting and solidification cause the mechanical properties of the weld in some cases to deteriorate such as low tensile strength, fatigue strength, and ductility. The disadvantages also include porosity, oxidation, micro segregation, hot cracking and other micro structural defects in the joint. The process also limits the combination of the metals that can be joined because of the different thermal coefficients of expansion. The solid state welding is the process where coalescence is produced at temperatures below the melting temperatures of the base metal without any need for the filler material or any inert ambience in many cases. Examples of solid state welding are friction welding, explosion welding, forge welding, hot pressure welding, and ultrasonic welding. The three important parameters time, temperature and pressure individually or in combinations produce the joint in the base metal. As the metal in solid state welding does not reach its melting temperatures, there are fewer defects caused due to the melting and solidification of the metal. In solid state welding, the metals being joined retain their original properties as melting does not occur in the joint and the heat affected zone (HAZ) is also very small compared to fusion welding techniques where most of the deterioration of the strength and ductility begins.

Dissimilar metals can be joined with ease compared to fusion welding. Friction stir welding (FSW) is an advanced friction welding process. The conventional friction welding is done by moving the parts to be joined relative to each other along a common interface also applying compressive forces across the joint. The frictional heat generated at the interface due to rubbing softens the metal and the soft metal gets extruded due to the compressive forces and the joint forms in the clear material, the relative motion is stopped and compressive forces are increased to form a sound weld before the weld is allowed to cool. Friction stir welding is also a solid state welding processes; this remarkable up gradation of friction welding was invented in 1991 in The Welding Institute (TWI). The process starts with clamping the plates to be welded to a backing plate so that the plates do not fly away during the welding process. A rotating wear resistant tool is plunged on the interface between the plates to a predetermined depth and moves forward in the interface between the plates to form the weld. The advantages of FSW technique is that it is environment friendly, energy efficient, there is no necessity for gas shielding for welding aluminium. Mechanical properties as proven by fatigue, tensile tests are excellent. There is no fume, no porosity, no spatter and low shrinkage of the metal. Joining dissimilar and previously un weldable metals can be attempted by this unique process.

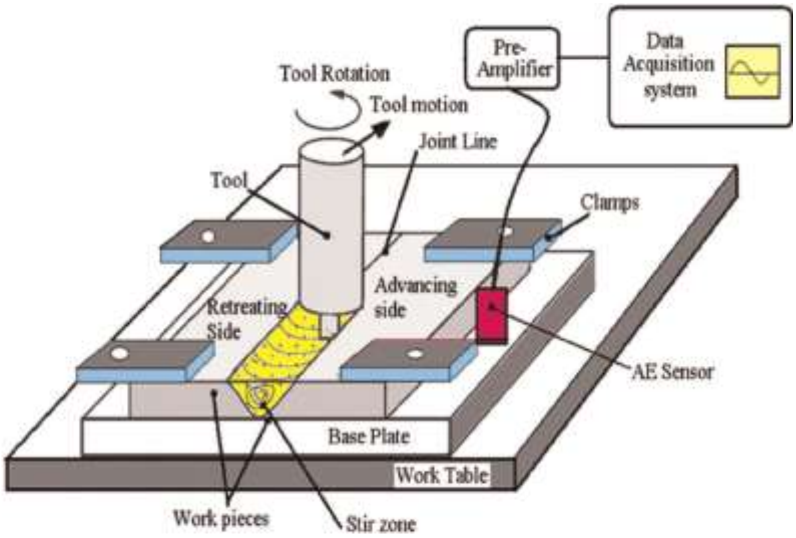

Fig1.1 Schematic Diagram of FSW Process

Introduction of 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, though some welds, known as autogenous welds, do not require it. 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 aluminium, 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. Manual gas tungsten arc welding is often considered the most difficult of all the welding processes commonly used in industry. Because the welder must maintain a short arc length, great care and skill are required to prevent contact between the electrode and the workpiece. Similar to torch welding, GTAW normally requires two hands, since most applications require that the welder manually feed a filler metal into the weld area with one hand while manipulating the welding torch in the other. However, some welds combining thin materials (known as autogenous or fusion welds) can be accomplished without filler metal; most notably edge, corner, and butt joints.

To strike the welding arc, a high frequency generator (similar to a Tesla coil) provides an electric spark; this spark is a conductive path for the welding current through the shielding gas and allows the arc to be initiated while the electrode and the workpiece are separated, typically about 1.5–3 mm (0.06–0.12 in) apart. This high voltage, high frequency burst can be damaging to some vehicle electrical systems and electronics, because induced voltages on vehicle wiring can also cause small conductive sparks in the vehicle wiring or within semiconductor packaging. Vehicle 12V power may conduct across these ionized paths, driven by the high-current 12V vehicle battery. These currents can be sufficiently destructive as to disable the vehicle; thus the warning to disconnect the vehicle battery power from both +12 and ground before using welding equipment on vehicles.

An alternate way to initiate the arc is the "scratch start". Scratching the electrode against the work with the power on also serves to strike an arc, in the same way as SMAW ("stick") arc welding. However, scratch starting can cause contamination of the weld and electrode. Some GTAW equipment is capable of a mode called "touch start" or "lift arc"; here the equipment reduces the voltage on the electrode to only a few volts, with a current limit of one or two amps (well below the limit that causes the metal to transfer and contamination of the weld or electrode). When the GTAW equipment detects that the electrode has left the surface and a spark is present, it immediately (within microseconds) increases power, converting the spark to a full arc.

Once the arc is struck, the welder moves the torch in a small circle to create a welding pool, the size of which depends on the size of the electrode and the amount of current. While maintaining a constant separation between the electrode and the workpiece, the operator then moves the torch back slightly and tilts it backward about 10–15 degrees from vertical. Filler metal is added manually to the front end of the weld pool as it is needed. Welders often develop a technique of rapidly alternating between moving the torch forward (to advance the weld pool) and adding filler metal.

The filler rod is withdrawn from the weld pool each time the electrode advances, but it is never removed from the gas shield to prevent oxidation of its surface and contamination of the weld. Filler rods composed of metals with low melting temperature, such as aluminium, require that the operator maintain some distance from the arc while staying inside the gas shield. If held too close to the arc, the filler rod can melt before it makes contact with the weld puddle. As the weld nears completion, the arc current is often gradually reduced to allow the weld crater to solidify and prevent the formation of crater cracks at the end of the weld.

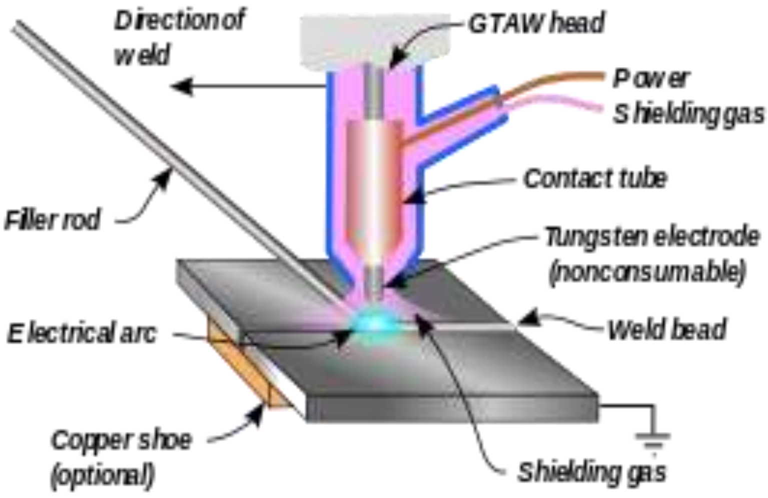

Fig. 1.2 Schematic Working of TIG Welding

II. LITERATURE SURVEY

Mofid et al. (2012) demonstrate the use of submerged friction stir welding (SFSW) under water as an alternative and improved method for creating finely grained welds. A constant tool rotation rate of 300 rpm and travel speed of 50 mm/min was used. The air welded specimen had a relatively larger volume fraction of an intermetallic compound, higher peak temperature in stir zone and significantly higher hardness in the weld center. The present study suggests that submerged friction stir welding under water resulted in lower peak temperature and because of lower heat input intermetallic compounds formation was limited.

Sharma (2012) investigate the effect of varying welding parameters on microstructure and mechanical properties of high strength Al–Zn–Mg alloy AA7039 using friction stir welded by varying welding and the rotary speed of the tool. The friction stir welding (FSW) process parameters have great influence on heat input per unit length of the weld, hence on temperature profile which in turn governs the microstructure and mechanical properties of welded joints. There exits an optimum combination of welding and rotary speed to produce a sound and defect free joint with a microstructure that yields maximum mechanical properties. The mechanical properties increase with decreasing welding speed/ increasing rotary speed i.e. with increasing heat input per unit length of welded joint. The high heat input joints fractured from heat affected zone (HAZ) adjacent to thermo-mechanically affected zone (TMAZ) on advancing side while low heat input joints fractured from weld nugget along the zigzag line on advancing side.

Malarvizhi et al. (2011) fabricated AA2219 aluminium alloy square butt joints without filler metal addition using gas tungsten arc welding (GTAW), electron beam welding (EBW) and friction stir welding (FSW) processes. The effect of three welding processes on fatigue crack growth behaviour is reported in this paper. Transverse tensile properties of the welded joints were evaluated. Microstructure analysis was also carried out using optical and electron microscopes. It was found that the FSW joints are exhibiting superior fatigue crack growth resistance compared to EBW and GTAW joints. This was mainly due to the formation of very fine, dynamically recrystallised grains and uniform distribution of fine precipitates in the weld region.

Balasubramanian et. al. (2011) studied the understanding of the material flow behaviour during friction stir channelling (FSC) is essential to produce consistently stable and continuous channels in monolithic plates. The channels were fabricated in Al6061-T6 alloy using FSC and the process forces were measured using a high frequency data acquisition system. Polar plots of the net resultant force acting on the tools are plotted and correlated with the process parameters and channel features. The magnitude and direction of the net forces acting on the tool are analysed to understand the material flow behaviour and the occurrence of channels in the nugget.

E. Cerri et. al. (2011) in the present study focuses on double-lap Friction Stir Welded (FSW) joints in 2024T3 and 7075T6 aluminium alloys subjected to several post-welding-heat treatments at warm (typical aging) and high temperature (solution range) followed by room temperature deformation (tensile tests). The effect of post-welding-heat treatments on the microstructure and mechanical properties of double lap FSW joints were investigated.

Polarized Optical Microscopy (POM) and Scanning Electron Microscopy (SEM) analysis revealed a progressive change in grain size and morphology in high temperature post-welding-heat treated joints, leading to Abnormal Grain Growth in the stir zone. Stress–strain curves are rather flat for 200_ and 300 _C post-welded heat treated joints while, for the other set of samples, stress increases with a strain to reach maximum stress of 140–160 MPa. Micro-hardness profiles measured on transversal sections of post-welded heat treated joints reveal conditions (temperature and time) of hardness homogeneity at the top, bottom, and central nugget zone and/or along the whole measured profile. When homogeneity is reached, fracture occurs in the nugget. A relationship between hardness and tensile properties has been applied in the nugget.

Lemmen et. al. (2011) presents the macro and microscopic fractography performed on fractures from fatigue cracks through friction stir welded joints. The welds were placed at different angles in the various specimens to study the influence of the yield strength and residual stress on fatigue crack growth. As a result, different behaviour was observed at the macro level, depending on the type of alloy and orientation of the weld. The variations in rotation of the crack plane raised a number of questions regarding the mode of loading, i.e. mode I or mode II. The purpose of this study was to investigate the fracture surfaces at the microscopic level to find explanations for the local macro behaviour. Special focus was placed on the fracture surfaces on which features were observed indicating mode II fatigue crack growth.

III. EXPERIMENTATION DETAIL

Preparation of Materials

A Rolled plate of 6mm thick aluminium alloy AA 6061were machined to the required dimensions (100 mm x 100 mm). The chemical composition and mechanical properties of AA 6061 are given in Table3.1and Table 3.2 respectively.

Table 3.1Chemical Composition of Base Material

Si	Fe	Cu	Mn	Mg	al
0.57	0.35	022	0.12	1.1	Bal

Table 3.2 Mechanical Properties of Base Material

Ultimate Tensile Strength (MPa)	Elongation	Hardness Hv
280	20	100

3.3 Selection of Tool Material and Tool Design

A proper selection of tool material and tool design plays a vital role to achieve good mechanical as well as microstructural properties with the Friction stir welding process. The tool steel classification system has been developed in which the commonly used tool steels are grouped into seven major categories. From to the various options of steels and alloys available it was necessary to select appropriate steel with specific characteristic behaviours that would apply to joining of aluminium alloys. This tool steel selection was also motivated by its cost and availability. It can be seen from Literature review that the tool material have a great influence on weld appearance and quality. That is why an appropriate tool material selection necessary to produce sound joints fabricated by friction stir welding of aluminium alloy. The chemical composition of selected material High chromium high carbon steel is presented in Table 3.3

Table 3.3 Chemical Composition of High Chromium High Carbon Steel

Elements	C	Mn	Si	Cr	Ni	Mo	V	Co	Cu	P	S	Fe
Wt%	1.40-1.60	0.60	0.60	11-13	0.30	0.7-1.20	1.10	1.10	0.25	0.03	0.03	Balance

Trial Experimentation for Friction Stir Welding

In this study, trial experimentation was performed using different parameters of i.e. tool rotational speed, welding speed, pin diameter, shoulder diameter, tilt angle. Different ranges of selected parameters were varied to find the optimum range of the parameters. One specimen for each parameter with constant value was used to set the best parameters.

At lower tool rotational speed the welding obtained was having defects due to improper heat generation. At higher tool rotational speed the welding obtained was also not proper due to excessive heat generation. Similarly, the range of the welding speed and shoulder diameter was selected. From trial experimentation, it was concluded that rotational speeds of 1200 rpm and 1500 rpm generate best results. It was also observed that welding speeds of 40, and 60 mm/min gave best joints, tool shoulder diameter was selected 18 mm and 21 mm. The welding parameters are presented in Table 3.4

Table 3.4: Process Parameters and their Ranges for Friction Stir Welding

S. No.	Tool Rotational Speed rpm	Welding Speed mm/min	Shoulder Diameter mm
1	1200	40	18
2	1500	40	18
3	1200	60	21
4	1500	60	21

Trial Experimentation for TIG Welding

The trial experimentation has been performed by using commercial settings of TIG welding apparatus as per handbook (Welding Aluminium designers and users). It was revealed that for a flat of the AA6061of thickness of 6 mm, the current rating may be varied from 70Amp to 250 Amp with gas flow rate 15 lt./min. It has been observed that below 80 Amp the welding joint was not properly made and at around 250 Amp burning of the specimen was begun. So, it was decided to fix the current range between 140 Amp to 170 Amp. This range gave a steady arc with least spatter. To study of welding of various aluminium alloys, the following parameters may be used:

3.10 Welding Parameters

- Welding Current.
- Welding Speed.
- Voltage.
- Gas Flow Rate.
- The diameter of Filler Wire.
- The thickness of Material to Weld.

In the present work, only one parameter was selected namely Welding Current. The selection has been made depending upon machine limitations.

Table 3.6: Process Parameter and their Ranges for TIG Welding

Specimen Designation	Current (Amp)	Gas flow (Lit/min)
1	120	15
2	140	15
3	160	15
4	180	15

Experimental Work

The test specimens used in the investigation were made using butt joints of AA6061.

Preparation of Test Specimen

After a study of material, the process of making the test specimen was done. All general precautions and procedure to be adopted for TIG welding of aluminium were studied. It was decided only AC TIG welding technique would be used for the preparation of test specimen. Steps followed for preparation of test specimen are as discussed below.

Preparation of Welding Station

The power supply used for TIG welding was AC. It was output current of up to 500 Amp. Since welding was done in open and not in the closed chamber. Adequate precautions were taken to prevent welding zone from atmospheric contaminations.

Argon gas of high purity and fit for welding was used for creating an inert atmosphere. Proper primary and secondary shielding was provided. As regard clamping of test pieces, no special clamps were used, the only pair of tongs served the purpose.

Edge Preparation

Each such strip was machined to obtain double V-groove, having an angle 65^0.

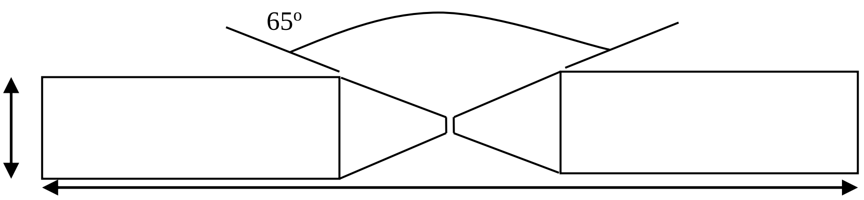

Fig: 3.2 Double V-Groove Test Specimen

Testing Procedures

In present study tested two types of testing, first was visual inspection performed for all welded specimens. Second mechanical testing consisting of two tests i.e. tensile test, Impact test of welded specimens and micro hardness tests and micro structure for the welded specimens.

Visual Inspection

Visual inspection was performed for all friction stir welded specimens and TIG welded samples in order to verify the presence of macroscopic external defects such as surface irregularities, excessive flash, lack of penetration, voids, and surface open tunnel defects. For the purpose of visual inspection cutting of welded specimen from cross section was taken to inspect the presence of any large defects which were visible to naked eye. It was observed in the visual inspection of the welded specimens that, no macro defects were present in all the specimens.

IV. RESULTS & DISCUSSIONS

Experimental Comparison for Tensile Strength for FSW & TIG

The experimentally evaluated transverse mechanical properties of Friction Stir and TIG welded AA 6061 aluminium alloy joints are presented in Table 4.1 and all the values are an average of three results from each joint. The unwelded parent metal showed a tensile strength of 290 MPa. From the two welded processes, the TIG joints showed the lowest tensile strength of 154MPa. This suggests that there is a 54% reduction in strength values due to TIG welding. FSW joints showed the highest tensile strength of 260 MPa. Though these values are lower than the base metal, the strength values are 36% higher than TIG joints. Of the two welded joints, the TIG joints showed the lowest elongation of 5.2 %. This suggests that there is a 45% reduction in ductility values due to TIG welding. FSW joints showed the highest elongation 7.2%. Though these values are lower than the base metal, the ductility values are 40% higher than TIG joints. The tensile properties, tensile strength, and elongation of FSW joint are superior compared to other joints as shown in Table 4.1. The combined effect of higher tensile strength and higher ductility of the FSW joint offers superior as compared to TIG joints. In the lower strength weld metal, as in the case of TIG joints, since the deformation and the yielding are mainly concentrated in the weld metal zone, the extension of the plastic zone is limited within the weld metal. Hence, the fracture toughness of the lower strength weld metal is not high. The comparison graphs between results of Friction Stir Welding and TIG welding are as shown in graphs.

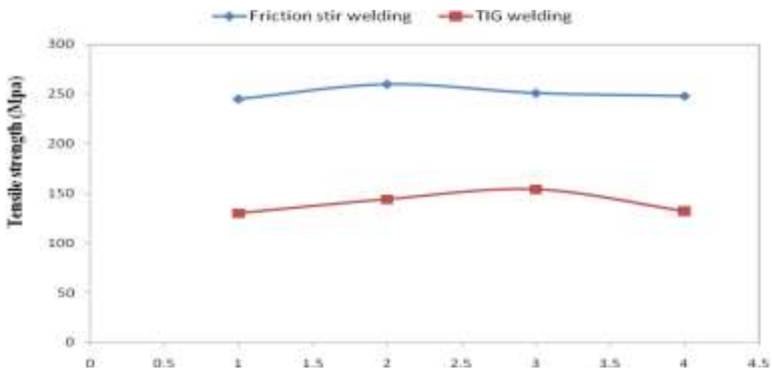

Fig. 4.1: Comparison between Tensile strength of FSW and TIG Welding

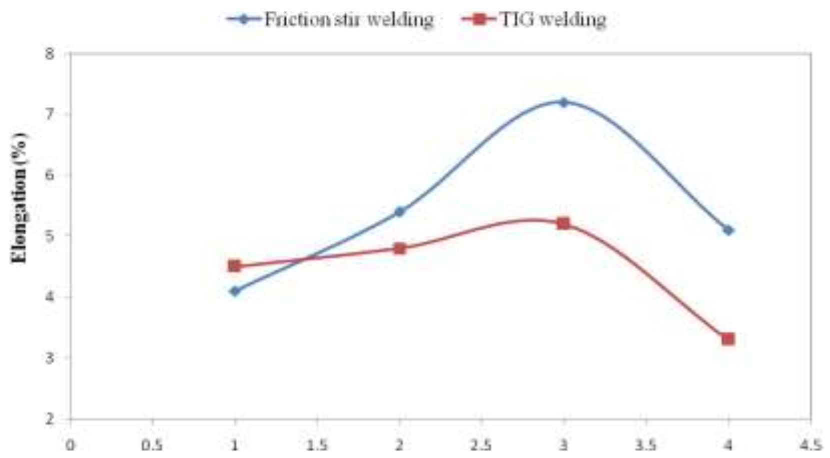

Fig. 4.2: Comparison between Elongation (%) of FSW and TIG Welding

Table: 4.1 Results of Friction Stir Welding

Experiment No.	Tensile Strength (MPa)	Percentage Elongation (%)
1	245	4.1
2	260	5.4
3	251	7.2
4	248	5.1

Table 4.2: Results of TIG Welding

Specimen Designation	Tensile Strength (MPa)	Percentage Elongation (%)
1	130	4.5
2	144	4.8
3	154	5.2
4	132	3.3

Microstructure

Optical micrographs of Friction Stir welded region of the joints are displayed the base metal contains coarse and elongated grains in the rolling direction. The weld region of TIG joint shows coarse and elongated grains normal to the welding direction. The weld region of the joint contains finer grains in the FSW joints compared to TIG welded joints. Fine evenly distributed precipitates in FSW process are one of the reasons for the higher strength of 6061 aluminium alloy joints. In TIG joint, the precipitates are completely dissolved in the matrix and very few particles are seen. In FSW joint, the particles are fine and uniformly distributed throughout the matrix and it is almost matching with the base metal micrograph. Often decreasing grain size and strength of the material increases. From the two welding processes, the weld region of FSW joint consists of very fine, dynamically recrystallised grains than TIG joints. The TIG joint contains coarse and elongated grains in the weld region. The material with finer grains obviously will have large grain boundary area. Not only the grain size influence, the size and distribution of strengthening precipitates behaviour of welded joints FSW joint contain a fine and uniform distribution of precipitates throughout the matrix compared to TIG welded joints. This was attributed to the superior tensile and hardness properties of FSW joints. The combined effect of very fine, dynamically recrystallised grains and uniform distribution of strengthening precipitates enhanced tensile and microstructural properties of the FSW joint as compared to TIG welded joints.

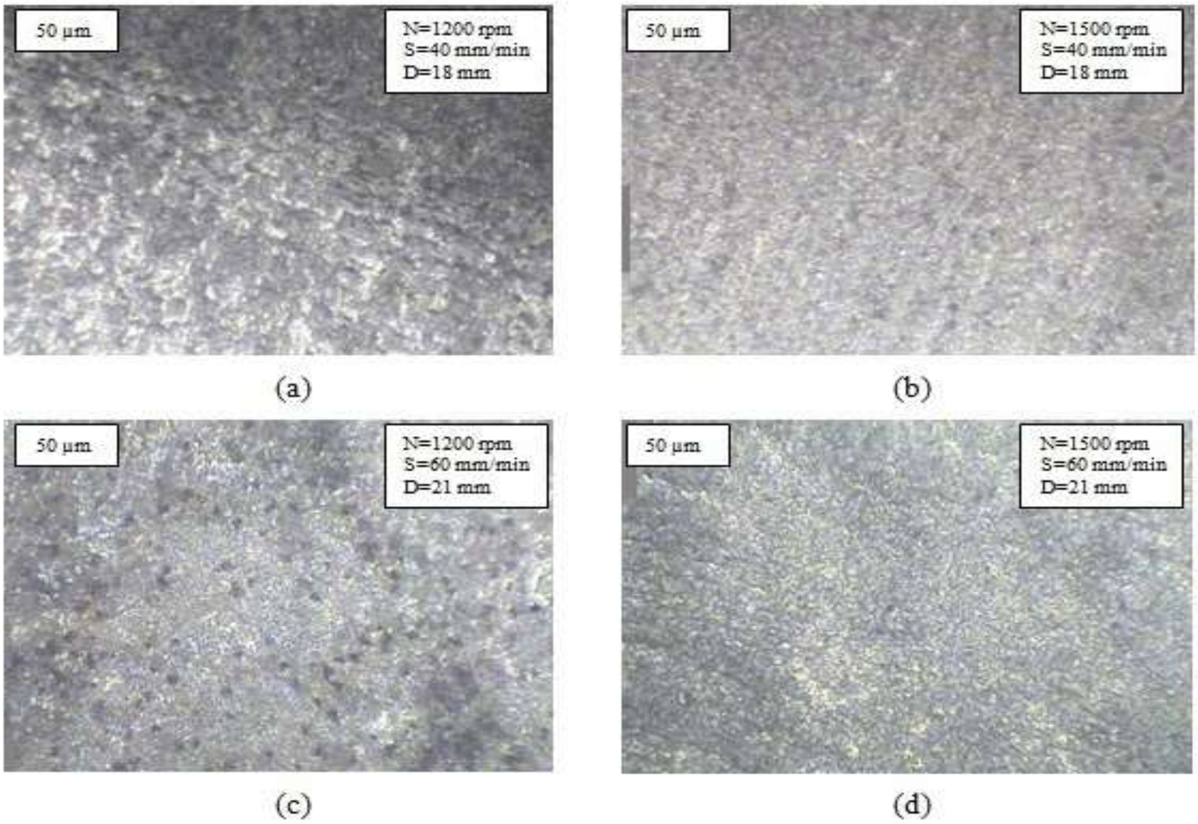

Fig. 4.6: Micro Structure

V. CONCLUSIONS

1. The Joint strength of FSW process and the TIG welding process was compared to the base metal. The Joint efficiency of FSW weld joint was 90% and the joint efficiency of TIG weld joint was 60%.
2. The impact strength of the FSW weld joint was higher than the base metal. But the impact strength of TIG weld joint was lower than the base metal.
3. Fine and equiaxed grain structure was observed in the stir zone in FSW process. But the course grain structure was observed in the TIG weld joints.

VI. SCOPE OF FUTURE WORK

1. The research work can be further taken up on different size of aluminium plate as per application or requirement of the industry. In present work only one parameter has been investigated, keeping other parameters constant. Study of other process parameters like electrode diameter, welding speed etc may be taking up.
2. Further experimentation can be performed to study possible interaction. Among variables that affect the performance of the process and some statistical tool like Taguchi method may be applied.

REFERENCES

1. A. Cabello Munoz, G. Ruckert, B. Huneau, X. Sauvage, S. Marya (2008)*," Comparison of TIG welded and friction stir welded Al–4.5Mg–0.26Sc alloy",* Journal of materials processing Technology, Vol.197, pp. 337–343.
2. A.Kumar, S.Sundarrajan (2009),"*Optimization of pulsed TIG welding process parameters on A. Squillac, A. De Fenzo,"* A comparison between FSW and TIG welding technique modification.
3. Cabibbo M, QueenMc H .J, Evangelista E, Spigarelli S, Paola Di M and Faichero A. (2007) "*Microstructure and mechanical property studies of AA6056 friction stir welded plate*" Journal of Materials Science and Engineering, pp. 86-94.
4. Ceschini L, Boromei I, Minak G, Morri A and Tarterini F. (2007) "*Effect of friction stir welding on microstructure, tensile and fatigue properties of the AA7005 composite"* Composites Science and Technology, Vol. 67, 2007, pp. 605-615.
5. Ceschini L, Boromei I, Minak G, Morri A and Tarterini F. (2007) "*Microstructure, tensile and fatigue properties of AA6O61/ friction stir welded joints* " Journal of' Composites, Part A applied science and manufacturing, Vol.38, 2007, pp. 1200-1210.

6. Dan Birsan, Elena Scutelnicu, Daniel Visan (2009), "*Behaviour Simulation of Aluminium Alloy 6082-T6 during Friction Stir Welding and Tungsten Inert Gas Welding"* Recent Advances in Manufacturing Engineering, pp 103-109 Design, Vol. 30, pp. 1288–1297.
7. E. Taban1, E. Kaluc (2007), "*Comparison between microstructure characteristics and joint performance of 5086-H32 aluminium alloy welded by MIG, TIG and friction stir welding processes*" Kovove Mater, Vol. 45, 2007, pp. 241–248.
8. H.W Zhang, J. T. Chen (2008), " *3 D modeling of material flow in friction stir welding under different process parameters* " Journal of Materials Processing Technology, Vol. 183, pp. 62-70.
9. L. Karthikeyan, V. S Senthil Kumar, D. Viswanathan, S. Natarajan (2007) "*Effect of Low Feed Rate FSP on Microstructure and Mechanical Properties of Extruded Cast 2285 Aluminum Alloy",* Journal of Material Science Technology, Vol 23, pp. 614-618.
10. Mustafa Kemal Kulekci, Erdinç Kaluç, Aydın Şık, Ozden Basturk (2007), "*Experimental Comparison of MIG and Friction Stir Welding Processes for en aw-6061-t6 (al mg1 si cu) aluminium alloy*" The Arabian Journal for Science and Engineering, Vol 35, pp. 321-341 of microstructure and pitting corrosion resistance in AA 2024-T3 butt joints.
11. P. M. G. P. Moreria, T. Santos, S. M. O. Tavares (2009) *"Mechanical and Metallurgical Characterization of friction stir welding joints of AA6061 with AA6082-T-6",* Journal of Materials and Design, Vol.30, pp. 180–187.

.