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COMPARATIVE STUDY OF FRICTION STIR WELDING AND TIG WELDING OF ALUMINUM (6061) ALLOY

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Abstract

Friction stir welding (FSW) has shown promising outcome in joining thermoplastics, Aluminum, surpassing traditional methods. This experimental study compares the welding of Aluminum 6061 material by Friction Stir Welding and TIG welding. The weld of aluminum plates of 6 mm thickness is obtained by FSW and TIG Welding. The microstructure analysis of weld is done using optical microscope and mechanical properties of weld is obtained using UTM. The tensile strength of the Aluminum weld using FSW is higher compared to the TIG welding. The welding strength regained is nearly 41.3% by the FSW and 15.6% by TIG welding. Coarse grain is obtained at the weld nugget in the FSW and finer grain is obtained in case of TIG Welding. Weld is less brittle in FSW than TIG Welding as the % elongation is 3.24 in FSW and 0.76 in TIG welding.

Keywords: *Friction Stir Welding, Tig Welding, Microstructure Analysis, Tensile Strength, % Elongation*

1. Introduction

Production of aluminum alloy has surpassed the use of steel in the manufacturing sector due to its high strength and ductile nature. The welding of aluminum lacks strength and more porosity on conventional welding thus development of friction stir welding helps to improve the strength and mechanical properties [1]. FSW is a modification of existing known method of joining metal through the frictional heating called as Friction welding. Friction welding is a known as the joining process which has in uses since more than 100 years. This method is generally known for joining material which is in rod or iron form and mostly for the circular surface as the rotational motion produces Frictional effect. FSW is a solid-state joining process for metallic and a few polymeric materials which is generally employed in applications in which the original material microstructure & properties must remain unchanged as much as possible after joining.

In FSW, the pin diameter is less than the shoulder and the welding is carried out by the generation of friction at the joint by varying different parameters as shown in Fig 1. The shoulder generates friction at the weld section. TIG welding is carried out for the same thickness and dimension of plate using tungsten as filler material. When compared to the Friction Stir Welding with conventional welding methods some of the advantages are

- Friction Stir welding is completed without any filler material.
- No use of gas and fumes.
- Low residual stress and distortion on the base material.
- Better Mechanical properties at the weld section.

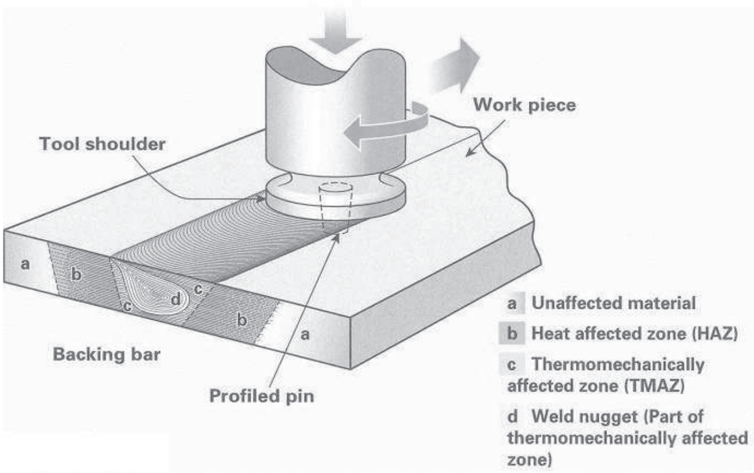

Fig 1: Friction Stir Welding

The different zones are created on the Metal during the welding process i.e., unaffected material, Heat Affected Zone (HAZ), Thermo-mechanically affected zone, stir zone.

Chemical Composition and Mechanical Properties of Aluminum 6061 alloy

The experiment is conducted on the sample piece of aluminum 6061 alloy with its Chemical composition and Mechanical Properties as:

Chemical Composition: Aluminum / Aluminum, Al: 97.9%, Magnesium, Mg: 1%, Silicon, Si: 0.60%, Copper Cu: 0.28%, Chromium, Cr: 0.20%

Mechanical Properties: Ultimate Tensile Strength: 276 MPa, Shear Strength: 207 MPa, Elastic Modulus: 68.9 GPa, Poisson's ratio: 0.33, Elongation:12-17%, Brinell Hardness Number: 95

2. Literature Review

Developed by The Welding Institute (TWI), the Friction Stir Welding (FSW) process was created and was patented in 1991 referring new terms of a manufacturing process at that period [2].

Peel et al (2003) use AA5083 Aluminium alloy for FSW by varying the welding conditions like tool design, rotation speed, and translation speed. The results of microstructural, mechanical property and residual stress investigations of four Aluminium AA5083 revealed that welding properties are influenced by the thermal input rather than the mechanical deformation by the tool [3].

Cavaliere et al (2006) studied the tensile i.e., mechanical and fatigue behavior of Friction stir welding of 2024 and 7075 alloys. It was found that 2024 fails in tensile test due to lower hardness and 7075 fails due to decreased fatigue life [4].

FSW is produced by rotating and plunging a specially-designed cylindrical, shouldered tool with a small diameter pin into the joint line between two butted plates [5].

In a 2006 study conducted by J. Adamowski a, M. Szkodo b a GSE, Ansaldo Energia, the Friction Stir Welding (FSW) of Aluminum alloy was examined. It was found that the tensile strength of FSW welds is directly proportional to the travel/welding speed. A decrease in hardness was observed in the weld region, with the most noticeable softening occurring in the heat-affected zone on the advancing side of the welds. This area corresponded to the failure location in tensile tests [6].

Sakthivel et al (2009) investigated the impacts of different welding speeds during friction stir welding (FSW) by changing traverse speed from 50 mm/min to 175 mm/min for analyzing the effect on metallurgical and mechanical properties of the alloy. In tensile testing, it was observed that the ultimate tensile strength decreases as the traverse speed increases [7].

Ghosh et al. (2011) noted that there’s a scarcity of friction stir welded joints in advanced high strength steel (AHSS). However, they pointed out that Friction Stir Welding (FSW) and Friction Spot Stir Welding (FSSW) offer the potential to join advanced high strength steels and mitigate issues related to Resistance Spot Welding (RSW) [8].

As stated by P. Cavaliere et al. in their 2009 study, friction stir welded joints exhibit superior fatigue performance only when they achieve optimal microstructure configurations. When the revolutionary pitch is within the range of 0.07-0.1, the process creates the ideal temperature and strain rate conditions for producing high-quality microstructures without defects for butt joints, resulting in sound welds [9].

3. Methodology

3.1 Literature Review

The available research papers and experimental results are analyzed. Many researchers have studied that the effect of one parameter at a time. However, the combined effects of the process parameters had not been studied extensively. This work aims to develop important and fundamental understanding for this technology by experimental work performed to obtain the joint of high strength and defect free. The material properties have to be studied properly.

3.2 Selection of Work Piece Material

Aluminum (6061) Alloy

The Friction stir welding and Tig welding is carried out on the Aluminum (6061) Alloy. 130 mm × 45 mm × 6mm of Aluminum piece is divided and held in the jig or support clamp for the welding procedure.

3.3 Tool Selection

FSW tool shoulders are generally less complex in their design than probes. The tool shoulder does not necessarily run parallel to the work piece surface, in simple linear welds the tool is often tilted such that the trailing edge of the shoulder penetrates the work piece and applies additional forging pressure. The tool shoulder profile significantly influences frictional heat generation during FSW. Tool shoulder profiles that restrict material flow, such as the scroll, give the greatest heat input, due to increased surface area. Thus, reduced scroll shoulder diameters is used. Machining of the tool is carried out in the lathe machine.

3.4 Heat Treatment of the tool

The need of the Heat treatment for the High Carbon Steel Tool is surface hardening. On Heat treatment the previous researcher has attained the tough and hard wearing on welding temperature. After Machining the tool, the Heat Treatment of the tool is carried out at around 700 Degree Celsius for the better result of the tool.

3.5 Experimental procedure

Initially the specimen was cut into 130mm × 45 mm × 6mm for the Nylon welding. A tapered steel tool having shoulder diameter 19mm, pin length 4.5 mm, and pin diameter 5.5 mm at the root and 4mm at the tip have opted. At first the procedure for nylon to nylon is carried out to read the parametric range. The plates will be fixed on a vertical milling machine along their length after fixing them in a proper position using mechanical clamps. The heat is generated by friction between the tool and the work piece which softens the material around the joint area and the rotation of the tool along with chemical formula $(C_{12}H_{22}N_2O_2)_n$ and in the same way, the joint of another specimen of 130mm × 45 mm × 6mm Aluminum 6061 is considered which is composed of different elements mixture.

The new specimen of same dimension of aluminum is again welded by the help of tig welding. The amount of time taken increases on starting the feed from one end to the other. The specimen obtained by the Tig welding is cut into small pieces for the mechanical properties test and Micro structure observation.

3.6 Testing for determination of Mechanical Properties and Microstructure Analysis

The Specimen is tested using universal testing machine by applying the load such that the different mechanical properties are observed through the graph. The cut piece of different specimen is applied for the load and the analysis of result is carried out. Microstructure analysis is examined optically which is taken perfectly flat and same level. On the uneven surface the as the viewing area is moved across the surface, and is difficult to have the whole field of view in focus. The view obtained and analysis is carried out on 200x and 100micrometer.

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5 Result and Discussion

4.1 Friction Stir Welding

S. No.	Spindle Speed (rpm)	Feed (mm/min)	Tilt Angle	Material Used	Material Used	Types of Joint
1	900	25	1	Aluminium	Aluminium	Butt
2	1100	25	1	Aluminium	Aluminium	Butt
3	1900	35	1	Aluminium	Aluminium	Butt

Table 1: Friction Stir Welding of Aluminum 6061 With varying parameters.

The initial specimen of 130mm × 45 mm × 6mm of aluminum 6061 is cut into half pieces and then Attached to the clamp positioned on vertical milling machine for the welding procedure with varying tool speed and Feed. For the generation of Friction, High carbon steel tool is used after the Heat treatment of the tool. The parameters taken for the joining Aluminum-Aluminum is given.

The Specimen is first welded at the Spindle speed of 900 rpm keeping the tool tilt angle as 1 Degree and tested for the Mechanical Properties and Microstructure analysis is carried out. Again, another piece of aluminum is welded at speed of 1000 rpm and 25mm/min feed and 1900 rpm at 35 mm/min. The welded piece gained after friction stir welding is shown.

Fig 2: Friction Stir welding at 900rpm

Fig: 3: Friction Stir welding at 1100 rpm

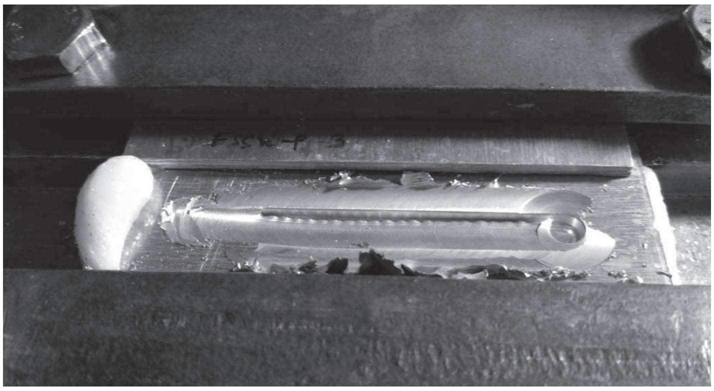

Fig 4: Friction Stir Welding at 1900 rpm Speed

As shown in Fig 2 the weld piece obtained at speed of 900 rpm and feed at 25mm/min, speed of 1100 rpm and feed at 25mm/min and 1900 rpm at 35mm/min. The pin of the tool plunges into the joint of aluminum at the start of welding and as the shoulder gives penetration to the welding piece generating friction at the joint resulting welding. The flash obtained is very low in the both specimens, at high speed higher amount of flash is seen and at the weld section we can see the tunnel defect and pores on visual inspection.

4.2 Tig Welding (Tungsten Inert Gas Welding) of Aluminum

Basically, still for the thin plates of aluminum 6061 Tig welding is preferred. We have experimented the joining of Aluminum 6061 Plates by tig welding process. The non heated specimen is welded during the process. As it uses non consuming electrode, the filler metal is used during the process which can be seen on the intersection. The 2 -3 mm of external layer is formed on the top of the intersection as the plates get welded.

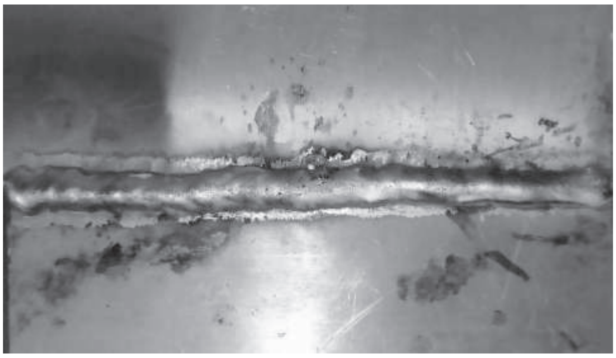

Fig 5: Tig Welding

4.3 Effect on Mechanical Properties by Friction Stir Welding

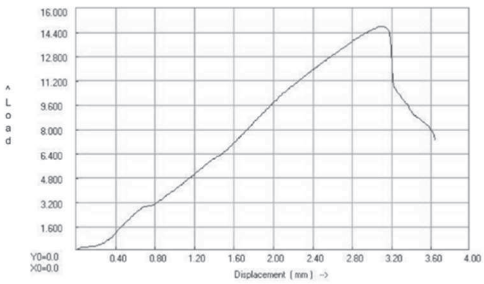

Fig 6: Load Vs Displacement at 900 rpm

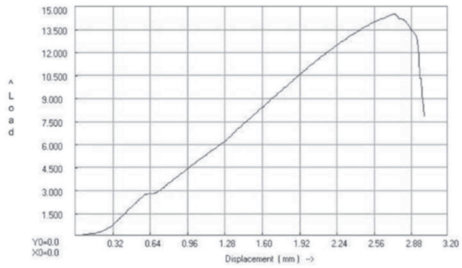

Fig: 7 Load vs Displacement at 1100 rpm

From Fig 6 The sample piece of 900 rpm speed original gauge length of 50mm with rectangular shape is tested on the universal testing machine. The final gauge length of 51.4mm is obtained after applying load. Tensile Strength of 112.5 MPa is attained with the yield load of 13.62 kN and Yield stress at 103.530 MPa.

From Fig 7 The sample piece obtained at speed of 1100 rpm speed had undergone at universal testing machine with original gauge length of 50mm. The final gauge length is 51.6mm after applying load. Tensile Strength of 114.29 MPa is attained with the yield of 13.3 KN and yield stress at 104.693 MPa.

4.4 Effect on Mechanical Properties by Tig welding

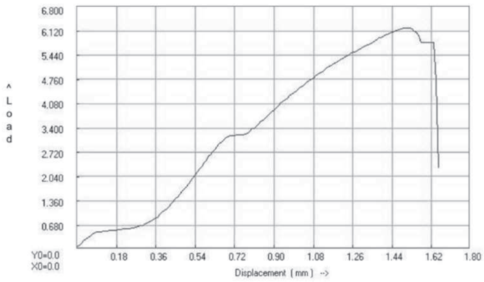

Fig 8: Load VS Displacement (Sample 1)

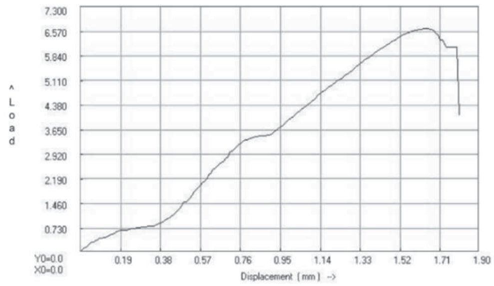

Fig 9: Load Vs Displacement (Sample 2)

The sample piece with original gauge length of 50mm with rectangular shape is tested on the universal testing machine. The final gauge length of 50.4mm is obtained after applying load. Tensile Strength of 43.7 MPa is attained with the yield load of 5.58KN and Yield stress at 39.39 MPa as shown in Fig 8.

From Fig 9 Another sample of original gauge length of 50 mm is applied load such that final gauge length of 50.3mm is obtained. Tensile Strength of 46.67 MPa is attained with the yield of 5.8 KN and yield stress at 40.674 MPa. As the load goes on increasing the displacement also increases. At the displacement of 1.63 mm the maximum of load is attained. The tensile strength obtained from the graph is 30-35 % of the strength gained during Friction Stir Welding Aluminum 6061.

4.5 Microstructure Analysis

4.5.1 Friction Stir welding

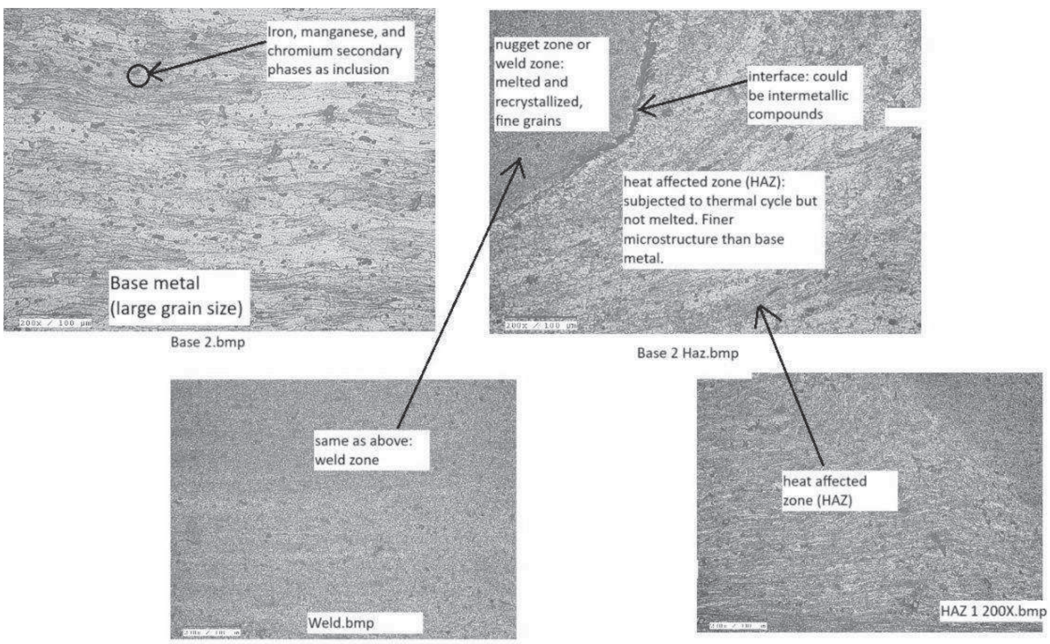

Fig 10: Microstructure Analysis of Friction Stir welding joint

The sample piece obtained went through the microstructure test. The different zones obtained on the periphery of the joint were established and analyzed. At the Base metal the grain structure is larger is size compared to the heat affected zone and the weld nugget as the intersection i.e., weld zone underwent through crystallization temperature during the process which is shown in Fig 10.

The chemical composition of Aluminum i.e., Iron Magness, Chromium is seen on the base as inclusion. The black dot spotted on the Fig 10 represent the chemical mixture of the alloy.

Fig 10 represents the Heat affected zone and weld nugget intersection. The generation of high temperature held recrystallization and formation of finer grain at the weld zone. The image at 200 times zoom could locate the intersection of the metallic compounds. On the advancing side the Equi axed grains structure is located.

4.5.2 TIG welding

The sample piece obtained went through the microstructure test. The different zones obtained on the periphery of the joint were established and analyzed. At the Base metal the grain structure is larger in size than compared to the base metal obtained of friction stir welding the process which is shown in Fig 11.

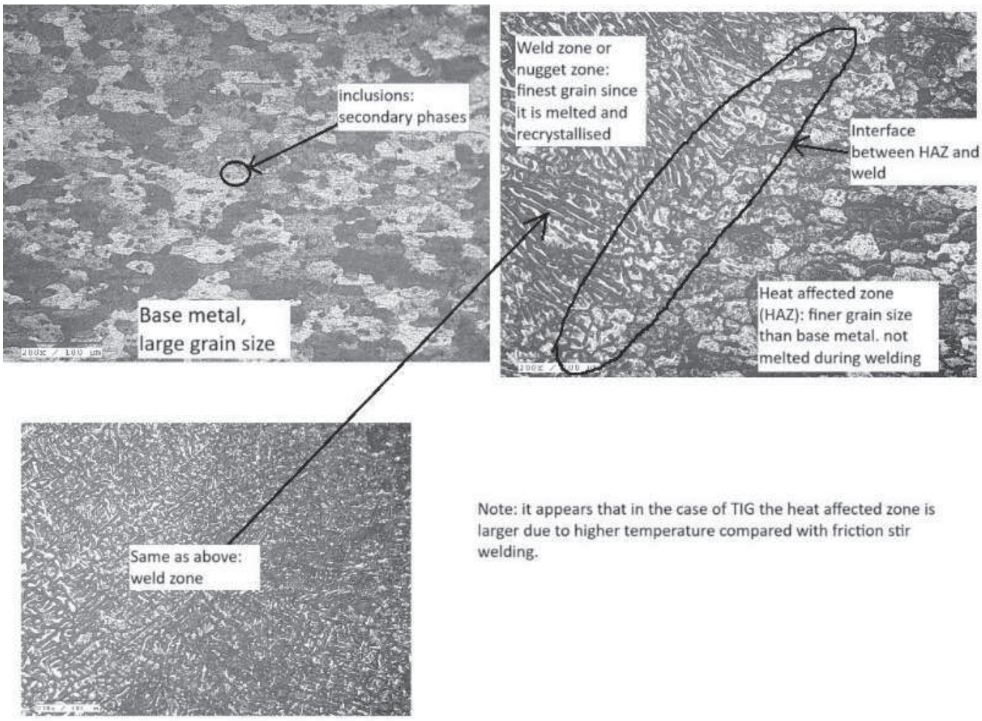

Fig 11: Microstructure analysis of Tig Welding Joint

The chemical composition of Aluminum i.e., Iron Magness, Chromium is seen on the base as inclusion. The black dot spotted on the Fig 11 represent the chemical mixture of the alloy.

Fig 11 represents the Heat affected zone and weld nugget intersection. The generation of high temperature held recrystallization and formation of larger finer grain at the weld zone. Dendrite like structure is found at the Weld zone. The image at 200x zoom could locate the intersection of the metallic compounds.

At the heat affected zone the grain observed is finer than that of the base metal though the melting metal of the particles is low to the near section. Finer Grain is observed on Heat affected zone. At the interface of the HAZ and Weld zone mixture of finer and large grain size is obtained.

5. Conclusions

Friction Stir Welding (FSW) in a solid state is a viable method for joining Aluminum Joints. An aluminum 6061 alloy specimen is joined using FSW at speeds of 900 rpm and 1100 rpm, 1900 rpm. The welded piece is then analyzed and compared to the weld piece from a Tungsten Inert Gas (TIG) welding. The tensile strength of the FSW joint is higher than that of the TIG welding joint. Additionally, the weld surface obtained during Friction welding exhibits finer grain compared to the TIG weld. In terms of tensile strength, Aluminum welds are stronger when created with FSW as opposed to TIG welding. The strength regained is approximately 41.3% with FSW, compared to around 15.6% with TIG welding. FSW results in a coarse grain at the weld nugget, while TIG Welding produces a finer grain. Furthermore, FSW welds are less brittle than TIG Welds, as indicated by the % elongation of 3.24 in FSW compared to 0.76 in TIG welding.

6. Suggestions and Recommendations

Though we have used tool of High Carbon steel tool changing of composition of tool and the tilt angle during the procedure can be studied. The change of the tool and the conical of Pin has shown various result as per the literature review which can be analyzed. Some of the points that can be taken during the process are

- Heat Treatment of tools for multiple times.
- Cutting of Specimen precisely for the testing such that the original weld is affected minimum.
- Analysis of result only can be done based on observation of microstructure size. More accurate result can be analyzed based on quantitative measure. For example, exact grain size can be calculated using Hall-Petch equation.
- Computational study of the FSW.

7. Acknowledgements

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