

# Optimization of Parameters of Friction Stir Welding OG AA-6061

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## Abstract

Friction-stir welding (FSW) is a solid-state joining process that uses a third body tool to join two faying surfaces. Frictional heat between the welding tool and the work pieces causes the latter to soften without reaching the melting point, allowing the tool to traverse along the weld line. It then mechanically intermixes the two pieces of metal at the place of joint; the softened metal can be joined using mechanical pressure (which is applied by the tool), much like joining clay or dough [1]. In this project, universal horizontal Milling Machine is used to weld the parts together. The parts being welded are made up of similar materials i.e. Aluminum alloy of 6061 grade. The rotational speed is varied from 1200 rpm to 1500 rpm while the welding speed is kept constant at 25 mm/min. The dimensions of the parts are (100mmx50mmx6mm) which are welded to form a butt joint. The effect of different tool pin profiles on the quality of the welded joint is also studied for welding. Different tool pin profiles considered are threaded, taper and cylindrical. The tools are manufactured on a Lathe machine. After the parts are welded, various practical tests are performed on the welded parts that include the tensile strength, microstructure study and the micro-hardness test. The experimental results proved that the highest tensile strength of the welded joint i.e., 81.073 N/mm<sup>2</sup> was achieved with the threaded tool profile at speed 900 rpm with feed 25 mm/min and the highest hardness value of 267HV was achieved with the round tool profile at 1500 rpm and feed of 25 mm/min.

## 1. Introduction

Friction Stir Welding is a solid-state process, which means that the objects are joined without reaching the melting point. It uses a tool of other material i.e., a tool profile to join the two joining surfaces. It mechanically intermixes the two pieces of metal at the place of the join, then softens them so the metal can reach their plastic state where they can be weld easily by using mechanical pressure. To achieve a good quality weld, various parameters such as tool profile, traverse speed, rotational speed of the tool etc. makes their crucial role in this. The development of new welding tool materials and geometries has made it possible to join materials such as steel and titanium in the laboratory environment and in a limited number of production applications. Furthermore, its applicability to aluminium alloys, in particular dissimilar alloys or those considered un-weld able by conventional welding techniques, such as tungsten inert gas (TIG) welding, make it as an attractive method for the transportation sector. Friction stir welding has been successfully applied for various similar [2] and dissimilar [3] aluminium alloys. The weld is formed by the deformation of the material at temperatures below the melting temperature. Sir Wayne Thomas at TWI (The Welding Institute) invented friction Stir Welding (FSW), and the first patent applications were filed in the UK in December 1991. FSW is considered to be the most significant development in metal joining in a decade and is a "green" technology due to its energy efficiency, environment friendliness and versatility. Recently, friction stir processing (FSP) was developed for micro-structural modification of metallic materials. As compared to the

conventional welding methods, FSW consumes considerably less energy. No cover gas or flux is used, thereby making the process environmentally friendly. In FSW no cover gas or flux is used, and does not involve any use of filler metal so that the properties of the joints are improved as compared to the parent metal [4]. It is difficult to obtain sound steel to aluminum joint or welding two similar aluminium alloys by using the conventional fusion welding processes. The friction stir process involves the translation of a rotating cylindrical tool along the interface between two plates. Friction heats the material which is then essentially extruded around the tool before being forged by the large down pressure. This heat along with the heat generated by the mechanical mixing process and the adiabatic heat with in the material, cause the stirred materials to soften without reaching the melting point. As the pin is moved in the direction of welding the leading face of the pin, assisted by a special pin profile, forces plasticized material to the back of the pin while applying a substantial forging force to consolidate the weld metal [5]. On one side, where the tool rotation is with the direction of the translation of the welding tool one peaks of the advancing side (AS) [6], whereas on the other hand, the two motions, rotation and translation counteract and one speaks of the retreating side (RS) [7] as shown in Figure 1. The welding of the material is facilitated by severe plastic deformation in the solid state involving dynamic recrystallization of the base material. FSW offers ease of handling, precise external process control and high levels of repeatability, thus creating very homogenous welds [8]. No special preparation of the sample is required and little waste or pollution is created during the welding process.

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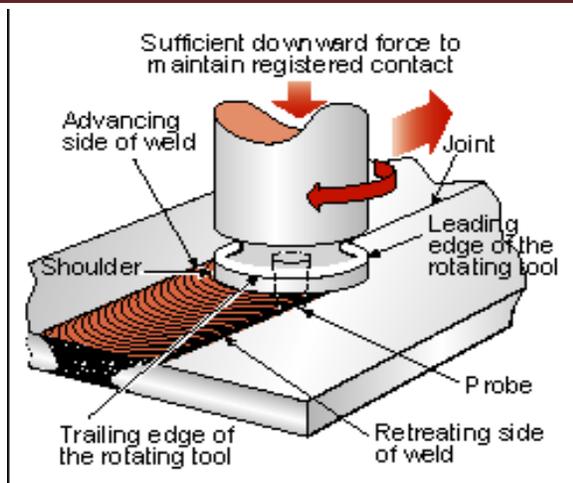


Fig. 1: Schematic diagram of the FSW process

## 2. Materials Used

The materials that have been used for welding in this work are Aluminium 6061 alloy. When compared to other materials, Aluminium is a softer metal. The density of Al 6061 is 2.7g/cm<sup>3</sup>. AA-6061 is a precipitation hardened aluminium containing magnesium and silicon as its major alloying elements. Originally called "Alloy 61S", it was developed in 1935. It has good mechanical properties and exhibits good weld ability. It is one of the most common alloys of aluminum for general purpose use. The material used for the tool is H13 hot die steel. H13 steel has its own advantages and disadvantages when compared to the other traditional materials used for tools i.e., Tungsten Carbide or HSS. H13 has an Ultimate Tensile Strength in the range of 965-1030Mpa. H13 Tool Steel is a versatile Chromium-Molybdenum Hot work Steel that is widely used in hot work and cold work tooling application. The hot hardness of H13 resists thermal fatigue cracking which occurs as a result of cyclic heating and cooling cycles in hot work tooling applications. Because of its excellent combination of high toughness and resistance to thermal fatigue cracking, H13 is used for more hot work tooling applications than any other tool steel. Because of its high toughness and very good stability in heat treatment, H13 is also used in a variety of cold work tooling applications.

## 3. Methodology

Traditionally, there has been a problem when welding dissimilar materials as the properties of the materials differ. Aluminium and Copper mostly cannot be welded using the conventional fusion welding processes like Arc welding, Gas welding etc. It was proved that these materials could be efficiently welded by using the Friction Stir Welding process. Various steps involved in the welding process are summarized in following steps.

Step I: START

Step II: Project proposal/ statement/  
objectives/ scope

Step III: Background study of the topic

Step IV: Project understanding

Step V: Literature review

Step VI: Methodology decided

Step VII: Welding process

Step VIII: Testing process

Step IX: Testing done is not satisfactory

Then repeat Step VIII otherwise go to Step X.

Step X: Results/ Discussions and END.

These are various steps that were followed during the completion of this work.

## 4. Literature Review

There are a lot of researches that has been done in the area of friction stir welding. Welds among a great no. of series of aluminium, magnesium, tungsten etc. has been performed by the help of friction stir welding. Some of researches related to welding of aluminium alloy series are as follows:

Nadim, A.A., et al. [9] In their experiment they used the different tool profiles which have been created using AutoCAD. The length of the tool is 75mm whereas the height of the tool probe is less than the thickness of the materials, i.e., 2.7mm. Initially a long Aluminum plate was taken and sectioned according to the required dimensions (100x55x3) all in mm. After the sectioning, the plates were properly clamped in the designed fixture setup for the welding operation. Subsequently, the tool (P20 steel material) was used and the welding process was completed at three different speeds while maintaining a constant feed. They concluded that The maximum tensile strength achieved was 81.073 MPa while welding at 900rpm with 25mm/min feed using the threaded tool. The maximum hardness value achieved was 267 HV while welding at 1500rpm, 25 mm/min feed using the round tool. The microstructure results obtained were found free from cracks, voids and non-metallic inclusions and slag levels were found satisfactory. It can hence be concluded that use of threaded and taper tool profiles yield better results than that of the round and square tool profiles.

Ramkumar, D., et al. [10] their research paper deals with the characterization of friction stir welded dissimilar Aluminium alloys AA 5052 and AA6061. The coupons of above metals were friction - stir welded using cylindrical pin tool using at constant speed of 710 rpm and at two different feed rates of 28 and 20 mm/min. Macrographs showed proper mixing due to effective stirring of cylindrical tool pin while keeping the lower feed rate. Correlating mechanical and metallurgical properties it is deduced that the sample welded at lower feed rate performed better in terms of ductility. Conclusion thus obtained is that Friction stir welds between AA 5052 and AA 6061 Al alloys sounds promising, having demonstrated excellent weld ability and performance characteristics.

Muruganandam, D., et al. [11] The comprehensive body of knowledge that has built up with respect to the friction stir welding (FSW) of aluminum alloys since the technique was invented in 1991 is reviewed in his paper. The basic principles of FSW are described, including metal flow and thermal history, before discussing how process parameters affect the weld microstructure and the likelihood of defects.

Finally, the range of mechanical properties that can be achieved is discussed. It is demonstrated that FSW of aluminum is becoming an increasingly mature technology with numerous commercial applications. He has succeeded in achieving this and then concluded in his paper that from an engineering perspective, there is a need to investigate

the occurrence and significance of flaws in friction stir welds. In particular, the influence of tool design on flaw occurrence and the development of nondestructive testing techniques to identify flaws in both lap and butt welds would be beneficial. Metal flow modeling may have a role to play here, though capturing this aspect of the thermo-mechanical behaviour remains a significant challenge.

Kovacevic, R., et al. [12] In their research friction stir welding (FSW) is a relatively new welding process that may have significant advantages: joining of conventionally non-fusion weld able alloys, reduced distortion and improved mechanical properties of weld able alloys joints due to the pure solid-state joining of metals. In this paper, a three-dimensional model based on finite element analysis issued to study the thermal history and thermo-mechanical process in the butt-welding of aluminium alloy 6061-T6.

Zhang, Z., et al. [13] represents the 3D material flows and mechanical features under different process parameters by using the finite element method based on solid mechanics. Experimental results are also given to study the effect of process parameters on joining properties of the friction stir welds. Numerical results indicate that the tangent flow constitutes the major part in the material flow. The shoulder can accelerate the material flow on the top half of the friction stir weld.

Simoes, D., et al. [14] Their work describes the thermo-mechanical conditions during Friction Stir Welding (FSW) of metals have already been subject of extensive analysis and thoroughly discussed in literature, in which concerns the FSW of polymers, From the study it was possible to conclude that, due to the polymers rheological and physical properties, the thermo-mechanical conditions during FSW are very different from that registered during welding of metals, leading to completely different material flow mechanisms and weld defect morphologies.

Song, M., et al. [15] A three-dimensional heat transfer model for friction stir welding (FSW) is presented in this paper; a moving coordinate is introduced to reduce the difficulty of modeling the moving tool. Heat input from the tool shoulder and the tool pin are considered in the model. The finite difference method was applied in solving the control equations. A non-uniform grid mesh is generated for the calculation. FSW experiments have been done to validate the calculated results. The calculated results are in good agreement with the experimental results. The calculation result also shows that preheat to the work piece is beneficial to FSW.

## 5. Experimental Setup

The materials used in this study, i.e., Al 6061 alloy & H13 hot die steel was procured in the form of cold rolled bars of proper dimensions with their composition as shown in Table 1 & Table 2.

**Table 1** Chemical composition of AA-6061

H13	C	Mn	Si	Cr	Mo	V
Balance	0.40	0.40	1.00	5.25	1.35	1.00

**Table 2** Chemical composition of H13steel

Al	Si	Fe	Cu	Mg	Cr	Others
Balance	0.59	0.4	0.26	0.96	0.3	0.5

The friction stir welding has been carried out by using a properly designed setup of the clamping fixture that allows the user to fix the two sheets (100mmx55mmx3mm) to be butt welded on a vertical milling machine. The vertical Milling machine provides an alternative way to produce friction stir welds when the actual FSW machine is not available. In the current study, the two types of tool profiles were designed and applied; namely,

- Plain Circular or round cylindrical body & tool profile as well, &
- Plain circular or round body with tapered tool profile.



**Fig. 2** Tool Snapshot: 1) Tapered (left) 2) Cylindrical (right)

The Fig. 2 represents the 2D diagrams of the tool profile. The length of the tool is 75mm whereas the height of the tool probe is nearly equal to the thickness of the materials, i.e., 5.9mm. Initially a long Aluminum plate was taken and sectioned according to the required dimensions (100x55x6mm). After the sectioning, the plates were properly clamped in the designed fixture setup for the welding operation. Subsequently, the tool (H13 steel material) was used and the welding process was completed at three different speeds while maintaining a constant feed. The welded plates can be seen in the Fig. 3 below which was welded using the threaded tool at 1200rpm with a feed of 25mm/min. The welded plates were first sectioned according to the tensile specimen test dimension standards and the tensile strength test was conducted on the Universal Testing Machine (UTM).



Fig. 3 Snapshot of AA plates welded at 1200 rpm



Fig. 4 Microstructure image at magnification 200X

**6. Testing Results**

**6.1 Microstructure Test & Results**

A carefully prepared specimen and magnification are needed for microscopic examination. Proper preparation of the specimen and the material’s surface requires that a rigid step-by-step process be followed. The first step is carefully selecting a small sample of the material to undergo microstructure analysis with consideration given to location and orientation. It is followed by sectioning, mounting, grinding, polishing and etching to reveal accurate microstructure and composition, the etchant used was 2% HF and K<sub>2</sub>CrO<sub>7</sub>+HNO<sub>3</sub>. A magnification of 200X was used for detailed viewing of samples using a metallurgical microscope.

Table 3 Microstructure test result

S.No	Test Parameter	Observed Result	Test Method
1	Microstructure at weld (200X)	The structure consists of fine inter-dendritic network of eutectic silicon in aluminium solid solution	ASM 9-2004

The test was conducted as per the ASME guidelines and was free from cracks and voids. The slag and inclusions level were found to be satisfactory. As we can see in Table III, that when the microstructure test is done at magnification of 200X then the observed result was that the welded material consists of fine inter-dendritic network of eutectic silicon in aluminium solid solution with the help of ASM9-2004. As well the microstructure image shown below in Figure 4 contains no voids and having a great strength.

**6.2 Hardness test and result**

The hardness test method consists of indenting the test material with a diamond indenter in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated shown in Table IV.

Table 4 Hardness Test Result

Location	Hardness(HV1)
WELD	76,78,80,79,81,80
HAZ	83,81,80,82,84,81
PARENT	91,89,93,92,89,92

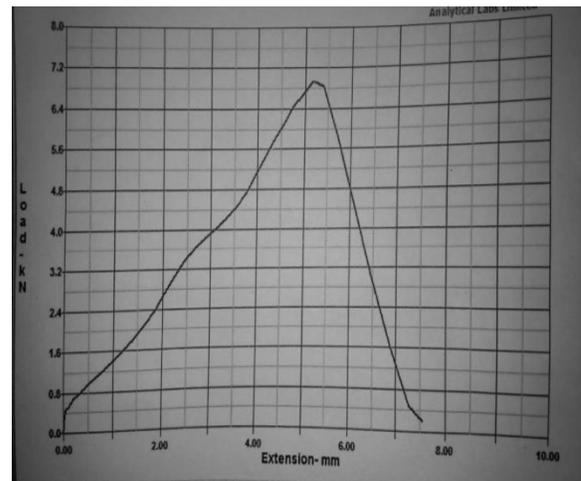


Fig. 5 Graph of Tensile Test (Load vs. Extension)

### 6.3 Tensile Test & Result

Transverse tensile test is performed on a Universal Testing Machine on workpiece of dimension (in mm) 19.00 X 6.25, of area 118.75 mm<sup>2</sup>, with a ultimate load of 6950 Newton, and this results into a Ultimate Tensile Strength of 58.5 MPa. The relationship graph among the load applied (in kN) and extension (in mm) produced in the workpiece is recorded and drawn into a graph as follows. As we can see that when the extension is 5.3 mm, then the load of 6.6 kN is applied and after that when the extension is further increased then the load gets decreasing as shown graphically in Figure 5.

### 7. Conclusions

The present review has demonstrated the extensive research effort that continues to progress the understanding of FSW of aluminium alloys and its influence on their microstructure and properties. The maximum tensile strength achieved was 81.073 MPa while welding at 900rpm with 25mm/min feed using the threaded tool. The maximum hardness value achieved was 267HV while welding at 1500rpm, 25 mm/min feed using the round tool. The microstructure results obtained were found free from cracks, voids and non-metallic inclusions and slag levels were found satisfactory. It can hence be concluded that use of threaded and taper tool profiles yield better results than that of the round and square tool profiles. Some of the observations concluded are as follows:-

- Friction stir welds between two similar plates of AA 6061 Al alloys sounds promising, having demonstrated excellent weld ability and performance characteristics,
- Cylindrical threaded pin has rendered excellent bondage between both work pieces of alloy AA 6061 by effective friction stir joining
- Extensive micro structural study gives better understanding of the grain structures and their influence on mechanical properties
- The mechanical and metallurgical characterizations have shown good agreement which is clearly evident from results obtained.

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