# A Review On Effect of Tool Geometry on Mechanical Properties of Friction Stir Welding of AA 6082-T6

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## ABSTRACT

*Friction stir welding (FSW) is a novel solid state welding process for joining metallic alloys and has been employed in several industries such as aerospace and automotive for joining aluminum, magnesium and copper alloys. The various parameters such as rotational speed, welding speed, axial force and attack angle play vital role in FSW process in order to analyze the weld quality. The aim of this study is to investigate the effect of rotational speed, welding speed and tool pin profile on weld quality. Friction stir welds find use for structural and other fabrication industries. This report provides details of FSW equipment used and explains the effect of welding speed and rotational speed on the mechanical properties of butt joints in AA6082-T6 material of 5mm thickness for different tool profiles. Weld tensile strength was measured and influence of process parameters was assessed. The weld's microstructure in various zones was analyzed using optical microscope. Microhardness measurements were performed on the weld's cross-sections. As tool profile is vital, Special Design (SD) profiled pins were designed and manufactured for trials. The appearance of the weld was studied for surface defects and found to be small in weld nugget.*

**Keyword: -** *Tool Pin, Welding Speed, Rotational speed etc….*

## 1. INTRODUCTION

FRICTION STIR WELDING (FSW) was invented at The Welding Institute (TWI) of the United Kingdom in 1991 as a solid-state joining technique and was initially applied to aluminum alloys. The basic concept of FSW is remarkably simple. A nonconsumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and subsequently traversed along the joint line Figure 2.1 illustrates process definitions for the tool and workpiece. Most definitions are self-explanatory, but advancing and retreating side definitions require a brief explanation. Advancing and retreating side orientations require knowledge of the tool rotation and travel directions. In Fig. 1.1, the FSW tool rotates in the counterclockwise direction and travels into the page (or left to right). In Fig. 3.1 the advancing side is on the right, where the tool rotation direction is the same as the tool travel direction (opposite the direction of metal flow), and the retreating side is on the left, where the tool rotation is opposite the tool travel direction (parallel to the direction of metal flow).

The tool serves three primary functions, that is, heating of the workpiece, movement of material to produce the joint, and containment of the hot metal beneath the tool shoulder. Heating is created within the workpiece both by friction between the rotating tool pin and shoulder and by severe plastic deformation of the workpiece. The localized heating softens material around the pin and, combined with the tool rotation and translation, leads to movement of material from the front to the back of the pin, thus filling the hole in the tool wake as the tool moves forward. The tool shoulder restricts metal flow to a level equivalent to the shoulder position, that is, approximately to the initial workpiece top surface. As a result of the tool action and influence on the workpiece, when performed properly, a solid-state joint is produced, that is, no melting. Because of various geometrical features on the tool, material movement around the pin can be complex, with gradients in strain, temperature, and strain rate. Accordingly, the resulting nugget zone microstructure reflects these different thermo mechanical histories and is not homogeneous. In spite of the local microstructural inhomogeneity, one of the significant benefits of this solid-state welding technique is the fully recrystallized, equiaxed, fine grain micro - structure created in the nugget by the intense plastic deformation at elevated temperature. As is seen within these chapters, the fine grain

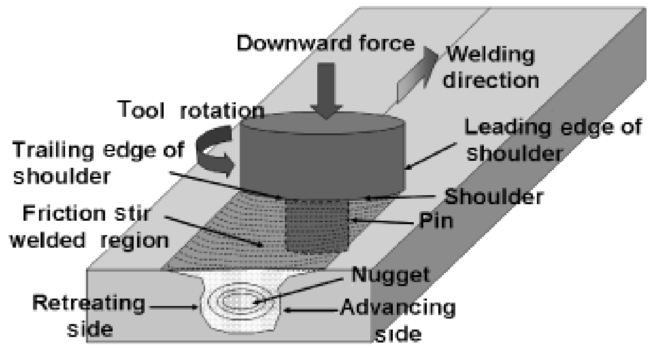



**Fig. 1.1 Schematic drawing of friction stir welding**

microstructure produces excellent mechanical properties, fatigue properties, enhanced formability, and exceptional super plasticity. Like many new technologies, a new nomenclature is required to accurately describe observations. In FSW, new terms are necessary to adequately describe the post weld microstructures.

## 2. LITERATURE REVIEW

**Yan et al., (2005)** used four different stir pins, two of them were column pin and taper pin and the other two were the same size but with screw thread, for FSW of 2014 aluminium alloy. The appearance of the weld is well and no obvious defect is found using this tool. The grain of the weld nugget is very fine and the precipitation distributes equally. The dimensional sizes of test pieces were 250mm×100mm×8mm. The shoulder diameter of the tool taken as 24mm. The length of the pin was 7.6mm and tilt angle for stir weld during experiment taken as 2°. The best quality weld was acquired using the taper with screw thread pin, the appearance of the weld was good, no obvious defects was found, and the microstructure of the nugget was even, the grain was fine, the precipitate distributions are even and the size of the precipitate is small. The tensile strength of the weld joint can reach consistently 75% of the base metal. He concluded that, the weld joint welded by the taper screw thread pin has the best mechanical properties.

**S.K. Chionopoulos et al., (2004)** investigated the effect of tool pin and welding parameters on friction stir welded (FSW) marine aluminium alloys for the eight different sets of parameters for fabricate the joint. Rolled plates of 5083-H111 aluminium alloy with dimensions 300mm × 150mm × 80mm were used in the experimental procedure. He considered eight different sets of parameters were used to fabricate the joints, while two a) conical shape pin, b) screw type pin geometries concerning the welding pins were used. From the results obtained it is concluded that only the conical pin geometry resulted in defect-free welds at specific welding parameters. As far as the screw type pin is concerned, there are some defects resulted in welds, most probably due to the specific design of the screw or due to the applied welding parameters which were not the optimal ones.

**Elangovan et al., (2007)** used five different tool pin profiles (straight cylindrical, tapered cylindrical, threaded cylindrical, triangular and square) to 33 FSP at three different tool rotational speeds. The formation of FSP zone has been analyzed and tensile properties of the joints have been evaluated and correlated with the FSP zone formation. The rolled plates of 6mm thickness, AA6061 aluminium alloy, were cut into the required sizes 300mm × 200mm by power hacksaw cutting and milling. From the result it is clear that the joints fabricated using square pin profiled tool with a rotational speed of 1200rpm showed superior tensile properties and exhibits better hardness in FSP zone.

**Kumar et al., (2008)** investigated the influence of axial load and the effect of position of the interface with respect to the tool axis on tensile strength of the friction stir welded joint of aluminium alloy 7020-T6. In this study, two different profiles of the tool were selected. Profile A consists of an un-chamfered shoulder and cylindrical pin with a flat end, while Profile B consists of a chamfered shoulder and a frustum shaped pin having rounded ends. Butt joints were made on a pair of 150mm × 100mm × 4.4mm sized sheets with no special or specific surface preparation prior to welding. For this particular study he select the parameter tool rotational speed of 1400rpm and traverse speed of 80mm/min with 0 tool tilt. From the result he concluded that chamfered shoulder having a frustum-shaped rounded-end pin produced a better quality weld and maximum efficiency.

**Mustafa et al., (2004)** prepared the weld joints of Al 1080 alloy using five different stirrers, one of them square cross-sectioned and the rest were cylindrical with 0.85, 1.10, 1.40 and 2.1 mm screw pitch. In this study, Al 1080 was used having dimensions 5mm× 25mm ×125mm. The welding process was carried out by rotating the stirrer at 1000 rpm and by moving the plates at 200 mm/min speed under a constant friction force. The best bonding was obtained with 0.85 and 1.10 mm pitched stirrers. Both the specimens welded using 0.85 and 1.10 mm pitched stirrers exhibited the same mechanical and metallographic properties. Bonding could be effected with square cross section stirrer but poor mechanical and metallographic properties were observed.

**Lee et al., (2003)** welded A356 alloys sheets using friction-stir-welding to observe the effect of mechanical properties at the weld zone by varying the welding speeds. The microstructures of the weld zone are composed of SZ (stir zone), TMAZ (thermo-mechanical affected zone) and BM (base metal). The microstructure of the SZ is very different from that of the BM. But the microstructure of TMAZ, where the original grains were greatly deformed, is characterized by dispersed eutectic Si particles aligned along the rotational direction of the welding tool. The mechanical properties of the weld zone are greatly improved in comparison to that of the BM.
**Rajakumar et al., (2011)** explored the influence of process and tool parameters on tensile strength properties of AA7075-T6 joints produced by friction stir welding.
Square butt joint configuration (300 mm × 300 mm) was prepared and the direction of welding was normal to the rolling direction of the base plates. From the result it is conclude that, the joint fabricated using the FSW process parameters of 1400 rpm (tool rotational speed), 60 mm/min (welding speed), 8 kN (axial force), with the tool parameters of 15 mm (shoulder diameter), 5 mm (pin diameter), 45 HRc (tool hardness) produced higher strength properties compared to other joints and also the defect free fine grained microstructure of weld nugget.

**Karthikeyan et al., (2009)** investigated the effect of friction stir processing (FSP) that can eliminate casting defects locally by refining microstructures, thereby improving the mechanical properties of material. The base material was cast aluminum alloy of 2285 grade at three different feed rates viz. 10 mm/min, 12 mm/min and 15 mm/min under two different tool rotational speeds 1400 and 1800 rpm. On processing, the work material was observed to have increased mechanical properties (tensile, yield strengths and ductility) properties.

The material was cut into rectangular pieces of dimensions 200×50 ×10 mm for processing. A milling machine was used for friction stir processing. The machine has a maximum spindle speed of 2000 rpm and 10 hp. A high speed steel (HSS) tool with a flat shoulder of 16 mm diameter and a cylindrical pin of 5 mm diameter, 4.7 mm long was used for processing. Processing was done at three different traverse speeds, such as 10 mm/min, 12 mm/min and 15 mm/min under two tool rotational speeds 1400 rpm and 1800 rpm. Only single stir passes were done during processing. On friction stir processing, the mechanical properties and microstructure of cast aluminum Al 2285 alloy are altered substantially. Around thirty percent improvements in yield and tensile strengths over the parent material were observed. The ductility values too increased around four fold on friction stir processing the parent material. Increase in tool rotational speed for a feed enhances the mechanical properties. Samples processed with a tool feed of 12 mm/min and 1800 rpm rotational speed were found to have better mechanical properties. The defects present in cast aluminum alloys are eliminated at the area of processing.

**Hirata et al., (2007)** developed the relationship between the microstructure of stir zone and the mechanical properties of FS-welded 5083 aluminium alloy. The microstructures of the stir zones consisted of fine equiaxed grains at various FSW conditions. The grain size of the stir zone decreased with the decrease in friction heat flow during FSW. The results shown that the micro structure and mechanical properties of the FS-welded 5083 Al alloy joints were improved by the refinement of grain size of the stir zone.

Rolled sheets of 5083-O aluminum alloy (Al–4.60Mg–0.73Mn–0.12Cr–0.03Fe–0.02Si) with a thickness of 3mm were used in FSW. Single-pass friction stir butt welds were made using an FSW tool with a shoulder and pin 12 and 4mmin diameter, respectively. The welding direction was parallel to the rolling direction. The inclination angle was set to 3◦. Several conditions of thermal generations were chosen, and the FSW conditions rotational speed (Rt), and welding speed (V) were changed from 500 to 1000 rpm and from 100 to 200 mm/min, respectively. The hardness of the stir zone increased with the decrease in friction heat flow because the grain size in the stir zone decreased with the friction heat flow. The tensile strength under each FSW condition was almost the same. However, the ductility was improved according to changes in the combination of Rt and V, and the formability in FS-welded 5083 Al alloy was improved by decreasing the friction heat flow.

**Hua et al., (2006)** conducted the experiments of friction stir welding for 5456 aluminium alloy with the changes of the tool tilt angle. The defects like lack of penetration or voids, or lazy S, which are unique to friction stir welding were reported. The typical welding defects of friction stir welding joint for 5456 aluminium alloy were analyzed and discussed. The microscopic examination of the nugget zone and fracture location of the weld confirms that the tilt angle can change the plastic material flow patterns in the stir zone and accordingly control the weld properties.

## 3. PROBLEM STATEMENT

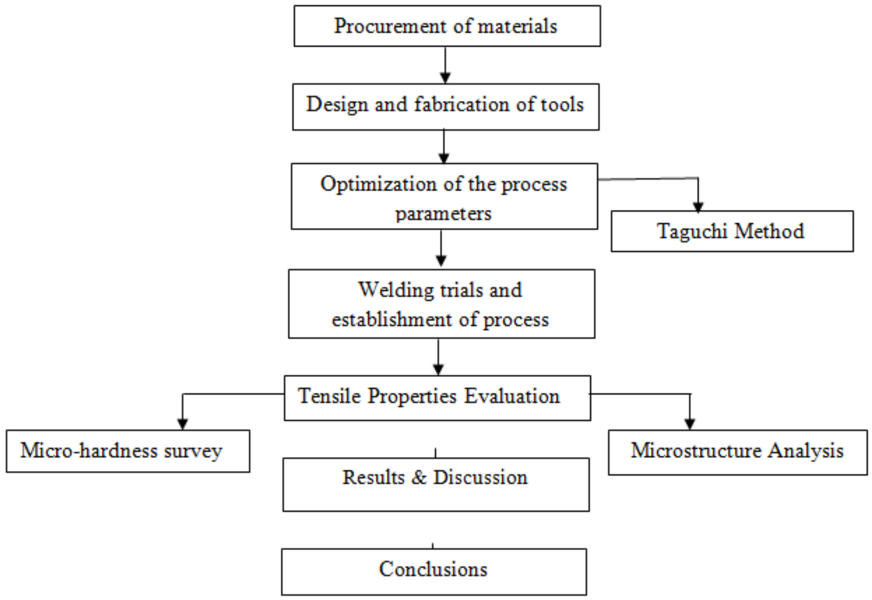
- From the above literature it is clear that tapered tool gives better result than conical and cylindrical tool and triangular tool gives better result than square, rectangular, pentagonal and hexagonal tool.
- Purpose of this project is to design new tool geometry which combines the result of tapered tool and triangular tool.
- In this work different to newly design tool geometry are considered to investigate the effect of this tool geometry on mechanical properties of friction stir welding.
- During, working with this special design of tool geometry various process parameters such as tool Rotational speed, transverse speed and tilt angle are varied.
- Taguchi's experimental design method is used to reduce number of experiments

## 4. OBJECTIVES

- Design and manufacturing of different tool geometries to find out interaction with base metal to get good quality weld
- Conduct FSW experiments on aluminum alloy for different combinations of rotational speed, welding speed.
- Investigation of joint for defects under varying conditions of process parameters
- Micro and Macro structural investigation of joint.

## 5. METHODOLOGY

This chapter discusses the methodology adopted for achieving the desired objectives through experimental work. All other details like friction stir machine used, tool used, the base material, plates preparation, welding procedure adopted, procedure used for specimens preparation for testing, testing equipment's and recording of the responses etc. is discussed under relevant headings as mentioned in the following sections. The trial experiments were conducted using Friction Stir Welding (FSW) on commercial AA6082-T6. Flow chart of experimental activities is described in Figure.




**5.1 MATERIAL AND PREPARATIONS OF SPECIMENS:**

A plate of 6 mm thickness of AA6082-T6 aluminum alloy having size 300mm x1450mm 6 mm was taken from the supplier. The chemical composition of the base material and mechanical properties are presented in Table .6.1 and 6.2 respectively. The required size plates of 80 mm wide and 300 mm long were taken from the sheet. Eighteen plates were prepared from the sheet and machined on the milling machine to make them parallel. The aim for machining both sides of the plates was to make them parallel for the FSW machine clamping system. The parallel plates enabled the uniformity in welding the gaps between the plates.

**5.2 EXPERIMENTAL WORK**

Experimental work done on the conventional vertical milling machine having specification are given below:

| Spindle Motor | Table Motor | Feed | Spindle Speed |
|---|---|---|---|
| 7.5 HP | 2.5 HP Auto | 63-900 mm/min | 300-1180 rpm |

Table: Specification of Vertical Milling Machine

De-four Vertical Milling Machine used to carried out an experimental work. Experimental setup use below:

Fig : Experimental Setup

**5.3 PROCESS PARAMETER**

For trial experiment different process parameters are considered while working with the different tool geometry. For this particular material AA 6082-T6 tool rotational speed is kept constant while welding speed and depth of cut kept varying.

| Tool Rotation Speed rpm | Welding Speed mm/min | Depth of cut mm | Tilt Angle Degree |
|---|---|---|---|
| 900 | 83-311 | 4.7-4.9 | 2˚ |

Table: Process Parameter for experimental work

**6. CONCLUSION**

This paper gives an overview of Effect of different tool pin profiles or geometries on mechanical properties of friction stir welding of AA6082-T6. It also combines the result of threaded tool and conical tool.

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