

# Heat transfer analysis in Friction Stir Welded AA6061 – Experimental method

<sup>1</sup> Arunagiri A, <sup>2</sup> Kalpana K,

<sup>1</sup> Assistant Professor, <sup>2</sup> Assistant Professor,

<sup>1</sup>Department of Mechanical Engineering, <sup>2</sup>Department of Production Engineering,

<sup>1</sup> ARM College of Engineering and Technology, Chennai.,

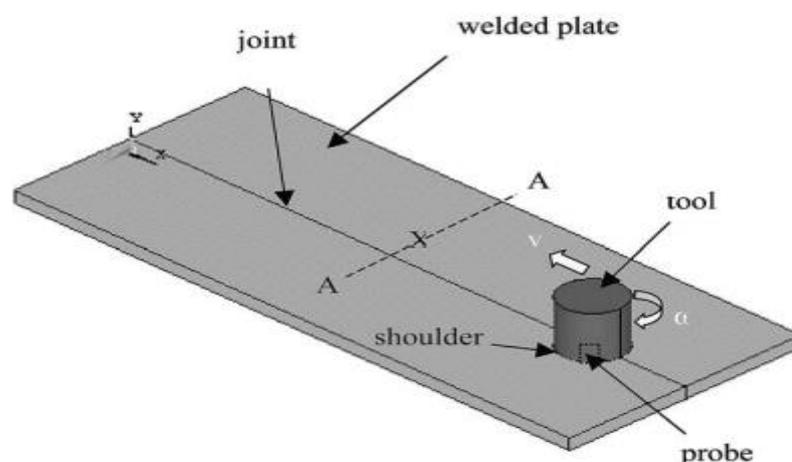
<sup>2</sup> Government College of Technology, Coimbatore.

**Abstract :** Friction Stir Welding (FSW) is a relatively new welding process that may have significant advantages compared to the fusion processes as follow: joining of conventionally non-fusion weldable alloys, reduced distortion and improved mechanical properties of weldable alloys joints due to the pure solid-state joining of metals. In this present study, an attempt has been made to study the effect of heat transfer and material flow of friction stir welded AA6061 aluminium alloy by experimental techniques. This experiment is carried out using two different tools (with groove and without groove). The influence of the tool on FSW properties is found. The temperature distributions during the process were studied using thermocouple (K-type thermocouple is used in the study). On comparing the results the welds carried out using tool with groove shows the best mechanical properties. The average temperature recorded during the weld is higher for the welds carried with the tool without groove.

**IndexTerms** - FSW, thermocouple, AA6061, mechanical properties.

## I. INTRODUCTION

As the problems associated with the fusion welding of aluminium (Al) alloys includes porosity, cracking, a high level of residual stresses, the significant reduction of baseline mechanical properties, and the need for multi-pass welding in thick sections. At this point the friction stir welding invented by Thomas and co-workers at TWI of the UK in 1991 as an alternative technology for fusion welding. Friction stir welding (FSW) [1] has been successfully applied in fabricating many critical load-bearing structures, e.g. rocket fuel tanks and high speed train bodies. The process is illustrated in Fig. 1, where a rotating cylindrical shouldered tool plunges into the butted plates and locally plasticizes the joint region during its movement along the joint line that causes a joint between the work pieces. In this process, the heat is originally derived from the friction between the welding tool (including the shoulder and the probe) and the welded material, which causes the welded material to soften at a temperature less than its melting point. The softened material underneath the shoulder is further subjected to extrusion by the tool rotational and transverse movements. It usually requires high level of torque and plunge force to generate enough heat energy for the welding process. The differences of temperature profile and the material flow between the advancing side (AS) and the retreating side (RS) lead to the differences of the microstructure and mechanical properties in both sides (Mishra and Ma 2005; Nandan et al. 2008a, b; Zimmer et al. 2009)[9]. It is expected that this process will inherently produce a weld with less residual stress and distortion as compared to the fusion welding methods, since no melting of the material occurs during the welding. Both thermal and mechanical aspects play a crucial role for the quality of the joints as well as for energy consumption. During FSW, the torque provides an indirect evaluation of the shear stress acting at the tool-workpiece interface, which in turn determines the heat generation and the plastic flow [4].



**Figure 1: A schematic illustration of FSW process [2].**

The tool geometry influences the property of welding. Pin thread is one of the most common geometrical features for the friction stir welding (FSW) tools. The main purpose of employing the pin thread is to improve the in-process material flow behaviors during FSW [3]. Zimmer et al. [5] performed an experimental investigation concerning the influence of the FSW plunge

processing parameters on the maximum generated force and torque. Yi et al. [6] studied the variation of the heat input during FSW of aluminum alloys by using calorimetric technique. Kumar et al. [7] analyzed the maximum temperature reached during FSW both experimentally and numerically and related the defects to the supplied heat input. J. De Backer et al (2016) [8] have developed the tool-work piece thermocouple (TWT), this method is a temperature measurement method for FSW. This TWT method measures the temperature at the interface of the tool and work-piece. It is based on the thermoelectric effect where the electric potential generated between the tool and work-piece relates the weld temperature.

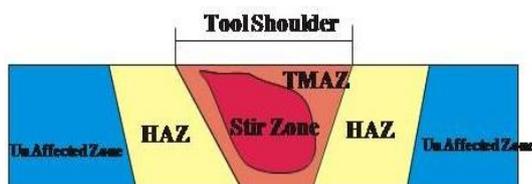


Figure 2: Various temperature distribution zone of FSW

In this present study, an attempt has been made to study the effect of heat transfer and material flow of friction stir welded AA6061 aluminium alloy by experimental techniques. This experiment is carried out using two different tools (with groove and without groove). The influences of the tool on FSW properties are found. H13 material was selected as the welding tool material and the workpiece material is AA6061. Aluminium alloy 6061 is selected for the study because of Aluminium alloy 6061 is a structural alloy; medium strength alloy with excellent corrosion resistance. The effects of tool pin geometries in the mechanical properties such as tensile strength, micro structure and microhardness of the welded joints were studied. The temperature distributions during the process were studied using thermocouple (K-type thermocouple is used in the study). On comparing the results the welds carried out using tool with groove shows the best mechanical properties.

## II. FSW CONDITION AND EXPERIMENTATION

### Specimen preparation

Rolled sheets with 3.0 mm of thickness of AA6061-T6 aluminum alloy were joined in butt configuration. The specimens were cut from a unique sheet by means of a bandsaw to a dimension of 50 mm × 100 mm (width × length). Then, the edges were grinded to ensure accurate correspondence of the faces. Before joining, the sheets were immersed in an ultrasonic bath (water and ethanol) to remove grease, oil, and powder. Then, they were covered by means of a thin graphite layer to increase the surface emissivity.

The tool is made up of H13 tool steel with the shoulder diameter 20mm. The experiment is carried with two different tools one with groove and the other without groove. In both the cases the tool shoulder diameter is kept constant as 20mm. Table 1 shows the FSW process parameters used in this study.

Table 1. FSW Process Parameters

Tool geometry	Rotational speed	Welding speed
With Groove Diameter = 20mm	1800 rpm	50 mm/min
Without Groove Diameter = 20mm	1800 rpm	50 mm/min

### Joining procedure and measurements

Friction stir welding experiments were conducted by means of a 3-axis milling machine. A schematic representation of the equipment is depicted in Figure 2. The sheets are fully in contact with the underlying steel plate, while they are clamped by means of six "fixing screws" with an end tip. This enabled to reduce the heat diffusion from the aluminum sheets to the overlying clamping frame. It also enabled to fully constraint the sheets during the joining process.

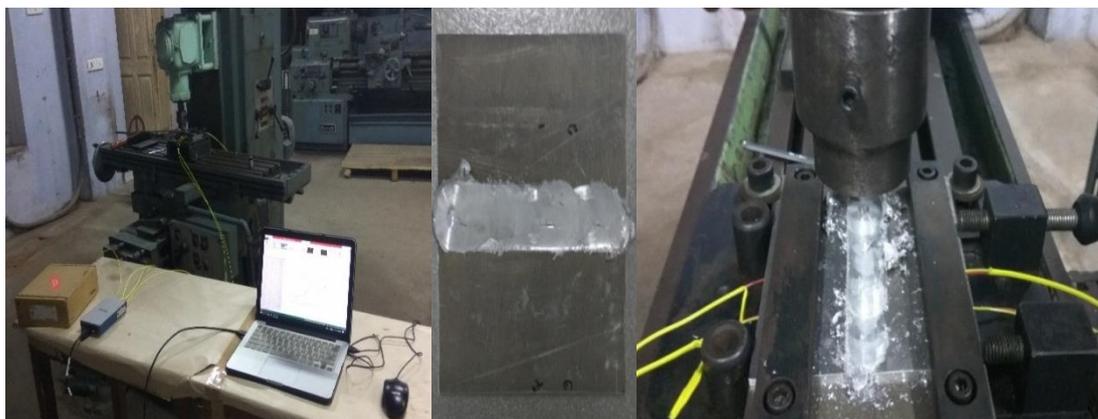


Figure 3: Overall setup

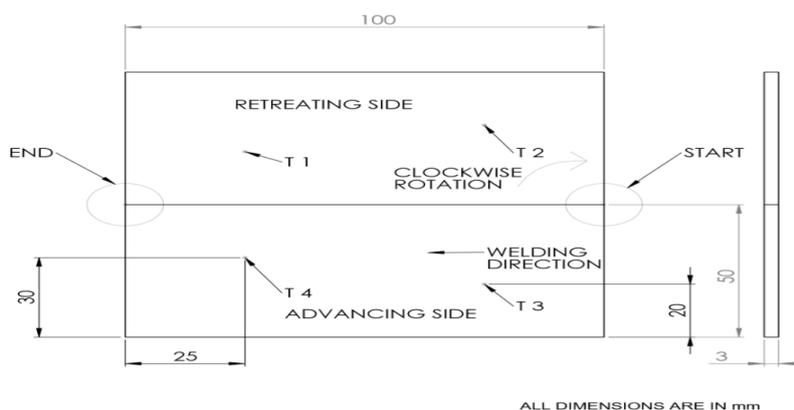


Figure 4: Locations for Thermocouple in FSW

The figure 4 shows the location of the thermocouple in the AA6061 plates, K- type thermocouple is used in this study. DAQ system is connected for data collection the DAQ is connected to the thermocouple and to the laptop, the various thermocouple temperature values are collected using this system.

**Tool Preparation**

The tool is prepared as per the dimension using the conventional machines. Further the tool is hardened and quenched in order to avoid the thermal stress. The figure 5 shows the tools used in this study, figure a represents the tool without groove and the figure b represents the tool with groove.



(a) TOOL WITHOUT GROOVE

(b) TOOL WITH GROOVES

Figure 5: FSW Tool for Experimentation (shoulder diameter of 20mm)

**III. Results**

The welded specimen is shown in the figure. Figure 6 (a) represents the welds carried out with groove tool and the figure 6 (b) represents the welds carried out with the tool without groove.

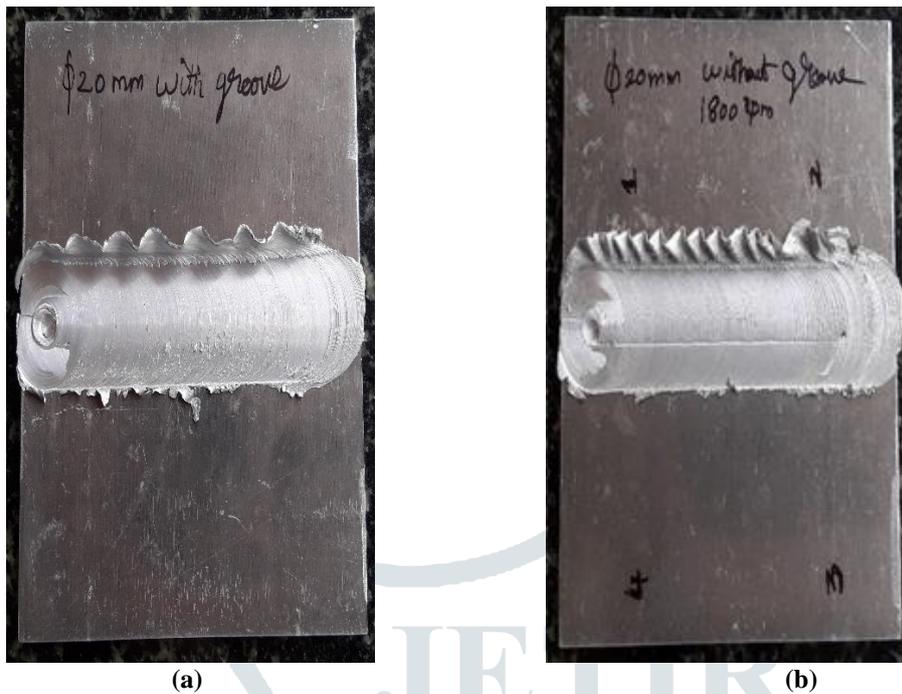


Figure 6: Weld Specimen of with and without groove pin tool

**Temperature distribution**

The temperature measured using the thermocouple and DAQ system is mentioned in the table. There are totally four thermocouples fixed in the four different position in the work piece and is been represented as TC1, TC2, TC3, and TC4.

Table 2 (a): Heat distribution value for tool with groove

Tool Groove	With	Thermocouple Point	Maximum Temperature	Process Parameter	
				Speed (rpm)	Feed Rate (mm/min)
Shoulder Diameter of 20mm	of	TC1	223.54	1800	50
		TC2	171.13		
		TC3	170.28		
		TC4	235.42		

Table 2 (b): Heat distribution value for tool without groove

Tool Without Groove	Thermocouple Point	Maximum Temperature	Process Parameter		
			Speed (rpm)	Feed Rate (mm/min)	
Shoulder Diameter of 20mm	of	TC1	231.42	1800	50
		TC2	178.88		
		TC3	183.13		
		TC4	244.98		

The temperature distribution profile recorded using thermocouple of various process parameter is shown in the figure 5.4 below. The temperature profile is recorded for all the experiment conducted by using K-type thermocouple with help of data acquisition system using lab-view software.

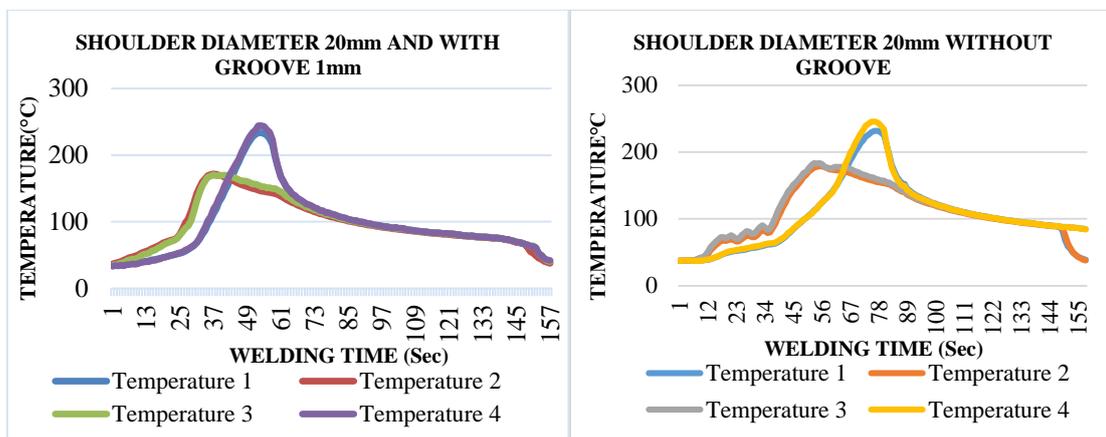


Figure 7 Process Parameters of Speed 1800 rpm and Feed rate of 50mm/min

From the graph and the table it is clear that the values of temperature measured on the welds carried out using the tool with the groove has less value as compared to the temperature distribution measured over the welds carried out using the tool without groove. It shows that the heat dissipation is more with the tool with groove. Thus results in defect free welds.

**Tensile strength test**

The tensile strength has been performed on the following above conducted experiments and the values are compared with base material and post weld material and results are shown in the figure.

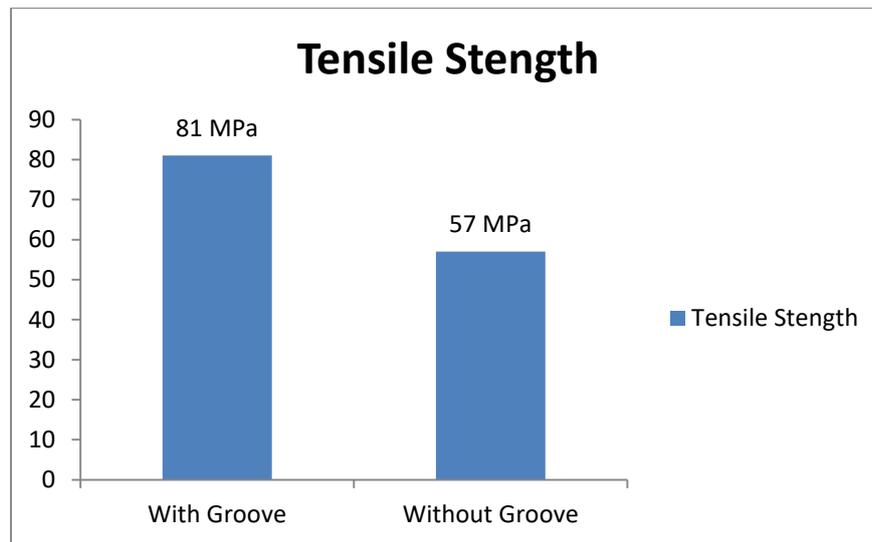


Figure 8: Tensile test specimens

The averages of three tensile test specimens were recorded. The tensile strength of the welded joint using tool with groove and without groove was 81% and 57% respectively. The degree of stirring is highly affected by the welding speed and the tool rotational speed [10,11]. The heat input is directly proportional to the tool rotational speed and axial force and indirectly proportional to the welding speed. Quality of weldments is based on the optimum heat input generated. Table 3 shows the tensile strength results and figure shows the graphical representation of the same.

Table 3: Tensile Strength of Welds using various Tools (with groove and without groove)

Tool geometry	Tensile strength
With Groove	81 MPa
Without Groove	57 MPa



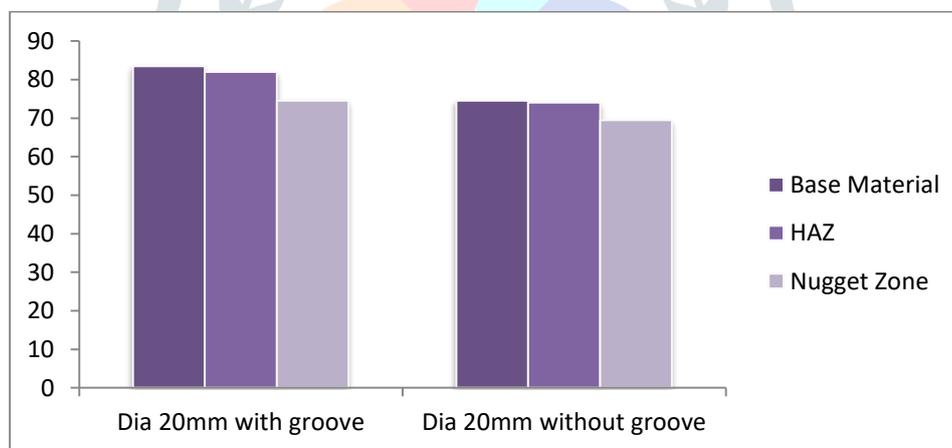
**Figure 9: Tensile Strength**

From the graph it is clear that the weld carried out with the groove tool has higher tensile strength compared with the weld carried with the tool without groove.

#### Microhardness

Where specific information is required on the hardness of sub-structures within the HAZ zone, it is necessary to carry out micro-hardness testing with loads in the 0.1 to 0.5 kgf range. For these applications purpose built micro-hardness testers are available using either the Vickers or Knoop test method. With these techniques, the area of interest is identified under a microscope and a hardness measurement made directly on the area of interest. Such techniques are applied to critical welding applications such as temper bead welding where a primary basis of acceptance of the welding technique is the hardness test.

Hardness Testing Welds and Heat Affected Zones, Vickers Hardness is the predominant measurement technique for welds and HAZs. The diamond indentation can be made using a range of loads from 1 to 100 kg.



**Figure 10: Microhardness measured at various zone**

From the microhardness results it is clear that the welds carried out using the tool with groove has the high hardness values.

#### IV. Conclusion

In this study, joining process was carried out by employing the friction stir welding technique. From the samples prepared under this joining technique, the performance of the tool geometry was determined with the tensile tests, temperature distribution and micro hardness characteristics. From the study, it can be concluded that, the tool with groove geometry weld obtained the high tensile strength compared with the tool without groove at 1800rpm and at the transverse speed of 50mm/min. It can also be concluded that the tool with groove enhances the heat transfer rate which in turn leads to a defect free welds.

#### REFERENCES

- [1] Mishra, R.S., Z.Y. Ma, Friction stir welding and processing. *Materials Science and Engineering: R: Reports*, 2005. 50(1-2): p.1-78
- [2] Chen, C. M., & Kovacevic, R. (2003). Finite element modeling of friction stir welding—thermal and thermomechanical analysis. *International Journal of machine tools and manufacture*, 43(13), 1319-1326.

- [3] G., Li, H., Wang, G., Guo, Z., Zhang, S., Dai, Q., ... & Shi, Q. (2018). Effects of pin thread on the in-process material flow behavior during friction stir welding: A computational fluid dynamics study. *International Journal of Machine Tools and Manufacture*, 124, 12-21.
- [4] Bhattacharya TK, Das H, Jana SS, Pal TK (2016) Numerical and experimental investigation of thermal history, material flow and mechanical properties of friction stir welded aluminium alloy to DHP copper dissimilar joint. *Int J Adv Manuf Technol* 88(1-4): 847-861
- [5] Zimmer S, Langlois L, Laye J, Bigot R (2009) Experimental investigation of the influence of the FSW plunge processing parameters on the maximum generated force and torque. *Int J Adv Manuf Technol* 47(1-4):201-215
- [6] Yi D, Onuma T, Mironov S, Sato YS, Kokawa H (2016) Evaluation of heat input during friction stir welding of aluminium alloys. *Sci Technol Weld Join* 22(1):41-46
- [7] Sedmak A, Kumar R, Chattopadhyaya S, Hloch S, Tadic S, Djurdjevic A, Cekovic I, Donceva E (2016) Heat input effect of friction stir welding on aluminium alloy AA 6061-T6 welded joint. *Therm Sci* 20(2):637-641
- [8] J. De Backer, A. C. F. Silva, G. Bolmsjo (2017) 'Temperature measurements during friction stir welding' *International Journal for Adv Manuf Technol* 88 :2899-2908 .
- [9] Zimmer, S., Langlois, L., & Laye, J. (2009). Experimental investigation of the influence of the FSW plunge processing parameters on the maximum generated force and torque. *International Journal of Advanced Manufacturing Technology*, 47, 201-215.
- [10] Satao YS, Yamashita F, Sugiura Y, Park SHC, Kokawa H. FIB-assisted TEM study of an oxide array in the root of a friction stir welded aluminium alloy. *Scripta Mater* 2004; 50:365-9.
- [11] Okamura H, Aota K, Sakamoto M. Behaviour of oxides during friction stir welding of aluminum alloy and their effect on its mechanical properties. *Weld Int* 2002;16(4):266-75.

