

# A Methodology for Friction Stir Welding of Aluminium 6061-T6 and 304L Stainless Steel

Nilesh V. Desai<sup>1</sup>, Dr. K. H. Inamdar<sup>2</sup>PG Student, Department of Mechanical Engineering, Walchand College of Engineering, Sangli, India<sup>1</sup>Associate Professor, Department of Mechanical Engineering, Walchand College of Engineering, Sangli, India<sup>2</sup>

**ABSTRACT:** Emerging trends in manufacturing such as light weighting, increased performance and functionality increases the use of multi-material, hybrid structures and thus the need for joining of dissimilar materials. Friction stir welding is one of the joining methods used for joining of similar and dissimilar metals. Although joining of dissimilar metals is quite difficult task. This paper discuss about the problems associated with welding of dissimilar metals and also methodology to join dissimilar metals. Aluminium 6061-T6 and 304L stainless steel is used as work material for the study. Welding of aluminium and stainless steel is possible with help of friction stir welding but proper selection of parameters is required. The common defects observed in conventional welding are eliminated in this type of welding. From the experiments it is clear that rotational speed and welding speed govern heat input in welding process.

**KEYWORDS:** Rotational Speed, Tool Offset, Tool Steel, Tungsten Carbide, Welding Speed

## I. INTRODUCTION

The joining of dissimilar materials can be done by mechanical fasteners, chemical bonding and thermal bonding. Mechanical means adds weight to overall component assembly which is not acceptable as it reduces performance of component. Chemical bonding is limited due to the difference in properties of joining metal. So in order to join the dissimilar metals thermal means is best among all. Fusion welding and solid state welding are the two major types of thermal bonding process. Friction stir welding is solid state process which is invented by the welding institute, United Kingdom, in 1991 [1]. The FSW process is carried out below the melting point of work material which will eliminate common defects induced during fusion welding. These defect are explained below:

### 1.1 Solidification cracking

This defect is similar to shrinkages in casting. The defects are arises due to high strain in weld bed or due to inadequate supply of liquid metals into the areas where it is needed to. These type of defects are mainly arises due to high temperatures during welding and then successive cooling develop cracks in weld bed.

### 1.2 Sensitization

This is also called as carbide precipitation or intergranular corrosion. The type of defect mainly occurs in steel. Stainless steel contains 18-20 % chromium. When steel is heated between 550 to 800°C and kept there for sometime then chromium combines with carbon and forms chromium carbide. This formation of carbides reduces chromium content from steel. The chromium depleted areas are suspected to corrosion, which is called as sensitization. This type of defects can be reduced by reducing carbon contents.

### 1.3 Porosity

The defects are associated with absorption of air and gases in liquid metals. The absorbed gases try to escape from weldment during cooling period which will develop blowholes and cracking. In order to avoid these defects shielding gases and proper machine set up is required.

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 12, December 2017

## 1.4 Hydrogen Cracking

The defects are produced due to absorption of hydrogen. Hydrogen has higher solubility in metals when they are in liquid state so when the metal is in liquid state hydrogen gets absorbed by it. During cooling cycle the solubility of hydrogen decreases and it tries to come out from the weld bed. This entrapment of hydrogen gas produces voids and results into cracking called hydrogen cracking

## 1.5 Thermal distortion

These defects are produced due to heating and cooling cycle induced during welding process. The workpiece to be joined are required to be held in fixture for welding. After heating, the stresses are induced into the material due to clamping. In cooling cycle these stresses tries to stabilize and which in turn distort the joint. The defects can be eliminated by preheating and post heating.

The defects discussed above are mainly due to the molten state of metal. Though these defects can be eliminated by some means it requires proper control of parameters and also not economical. So if we want to eliminate these defects we have to go for solid state welding process in which the metal is not melted but worked in plastic state. Friction stir welding is one of the solid state welding processes which is initially developed for aluminium alloy but now can be used for hard metals like steel, titanium alloys. Although, the joining of dissimilar metals require proper selection of parameters and method.

## II. WORKING PRINCIPLE

The process is schematically represented in fig.1. The plates are abutted along the edge to be welded and the rotating pin is plunged into the plates until the tool shoulder is in full contact with the surface of the plate. Once the pin is completely inserted, it is moved with a small tilting angle in the welding direction. Due to the advancing and rotating effect of the pin and shoulder of the tool along the seam, an advancing side and a retreating side are formed; the softened and heated material flows around the pin to its backside where the material is consolidated to create a high-quality weld [2].

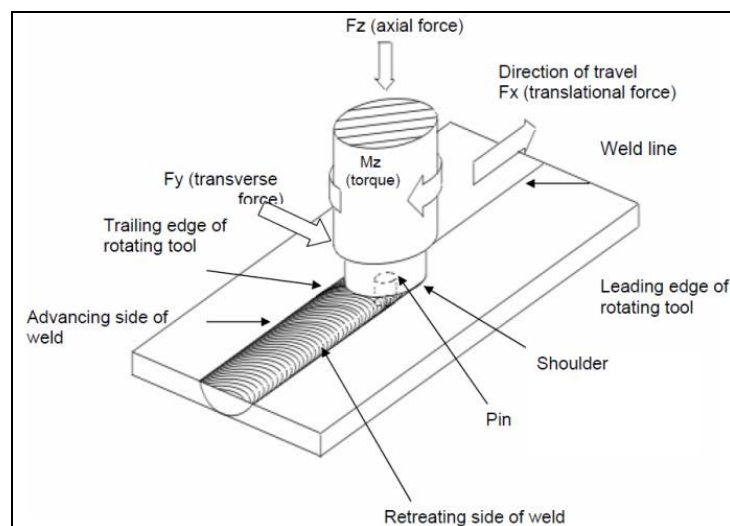


Figure 1: Schematic Diagram of FSW Process [2]

FSW has also been shown to eliminate or dramatically reduce the formation of hazardous fumes and reduces energy consumption during welding, reducing the environmental impact of the joining process. FSW can be used in any orientation without regard to the influence of gravitational effects on the process. These distinctions from conventional arc welding processes make FSW a valuable new manufacturing process with undeniable, economic, and

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 12, December 2017

environmental benefits. In early years, it was introduced for light alloys. Recently, high-performance tools materials are employed for FSW of high melting temperature materials such as titanium, nickel and steels

### III. LITERATURE SURVEY

Yazdipour and Heidarzadeh [3] studied the effect of tool traverse speed, offset and rotation direction during dissimilar butt friction stir welding of Al 5083-H321 and 316L stainless steel plates at a constant rotational speed of 280 rpm. The tensile and hardness tests were conducted to evaluate the mechanical properties of the joints. The results showed that defect free joint with the maximum tensile strength of 238 MPa was produced at a traverse speed of 160 mm/min, pin offset of 0.4 mm, and clockwise rotation condition. The reduction in tensile strength of the other joints was due to their surface and cross-sectional defects such as tunnel defect, voids, non-uniform distribution and large particles of the steel and microcracks developed in the interface of the dissimilar parts.

Siddiquee et al. [4] performed friction stir welding on austenitic stainless steel plates on an indigenously retrofitted vertical milling machine. AISI-304 equivalent grade stainless steel was welded by FSW using tungsten carbide tools with tapered cylindrical (conical) pin. The results of ANOVA showed the order of importance in which the parameters have affected the UTS in terms of percent contributions i.e. welding speed with (56.83% contribution), shoulder diameter (27.44% contribution) and tool rpm(15.73% contribution).

Ramachandran et al. [5] studied the effect of tool axis offset from the joint interface and geometry of the FSW tool pin on the mechanical and metallographic characteristics of dissimilar FSW welded aluminium alloy and HSLA steel. The constant FSW parameters used were; tool rotational speed of 500rpm, welding speed of 45 mm/min, and an axial load of 7 KN and tool tilt angle of 1.50°. The effect of tool axis offset was investigated by continuously changing the tool axis offset by keeping the tool traverse direction at an angle to the joint interface. FSW tool having TC pin with 100° taper angle has produced the best joint at a tool axis offset of 2 mm towards the Al alloy.

Uzun et al. [6] worked on joining of Al 6013-T4 alloy and 304L stainless steel using friction stir welding. The microstructure, hardness and fatigue properties of friction stir welded 6013 aluminium alloy to stainless steel have been investigated. The weld nugget, the heat affected zone (HAZ), thermo-mechanical affected zone (TMAZ) were observed under optical microscope. Fatigue properties of Al 6013-T4 and 304L stainless steel joints were found to be 30% lower than that of the Al 6013-T4 alloy base metal.

Chen and Kovacevic [7] performed experiments on Al 6061 and AISI 1018 steel having 6-mm thickness. Metallographic studies by optical microscopy, electron probe microscopy, and the utilization of the X-ray diffraction technique have been conducted. It was found that the intermetallic phases  $Al_3Fe_4$  and  $Al_5Fe_2$  exist in the weld zone. The tool was significantly worn during welding and is broken after traveling 100 mm at a rotational speed of 917 rpm. The wear of the tool significantly affects the structure of the weld, and the tool breakage was detected by the incorporated acoustic emission sensors.

Kakiuchi et al. [8] used aluminium 6061 and 304 stainless steel for the experimental work. They found that the tensile strength of 194 MPa was obtained in the condition of the rotating speed of 800 rpm and the tool offset of 0.2 mm. Near the welded boundary, the hardness decreased in the Al side due to the resolution of precipitates during the FSW process while the hardness increased in the steel side due to the work hardening.

Liu et al. [9] worked on thin sheets of aluminum alloy 6061-T6 and one type of advanced high strength steel, they observed that the maximum ultimate tensile strength can reach 85% of the base aluminum alloy. Intermetallic compound (IMC) layer of FeAl or Fe<sub>3</sub>Al with thickness of less than 1 μm was formed at the Al-Fe interface in the advancing side, which can actually contribute to the joint strength.

Watanabe et al. [10] tried to butt-weld an aluminum alloy plate to a mild steel plate by friction stir welding, and investigated the effects of a pin rotation speed, the position for the pin axis to be inserted on the tensile strength and the microstructure of the joint. The behavior of the oxide film on the faying surface of the steel during welding also was examined. The main results obtained are as follows. Butt-welding of an aluminum alloy plate to a steel plate was easily

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 12, December 2017

and successfully achieved by friction stir welding. The maximum tensile strength of the joint was about 86% of that of the aluminum alloy base metal. A small amount of intermetallic compounds was formed at the upper part of the steel/aluminum interface, while no intermetallic compounds were observed in the middle and bottom parts of the interface. The regions where the intermetallic compounds formed seemed to be fracture paths in the joint. Many fragments of the steel were scattered in the aluminum alloy matrix and the oxide film removed from the faying surface of the steel by the rubbing motion of a rotating pin was observed at the interface between the steel fragments and the aluminum alloy matrix.

Meran and Canyurt [11] worked on stainless steel plates that were butt welded by FSW method using 7.5 kW vertical head milling machine. The average grain size in the stirred zone was between 3 and 7  $\mu\text{m}$ , which is smaller than that in the base metal (BM). The average grain size in the HAZ was about 20  $\mu\text{m}$ , which is half of that of the BM fine-grained microstructures are present the welded area. The dark bands observed in the weld zone have also detected the microstructure of the transition zone. Dark and narrow bands do not consist of pores or cavities.

## IV. RESEARCH METHODOLOGY

From literature review the process parameters involved in FSW process can be understood. The various process parameters are: rotational speed, welding speed, axial force, tool geometry, tool material, tool offset, tilt angle, workpiece position and plunge depth. In order to obtain quality weld control over these parameters plays an important role. Rotational speed and welding speed are affect heat input. Axial force applied on the tool will affect the mechanical deformation of workpiece material. Tool material will be decided considering the workpiece material. For soft materials tools made from tool steel, stainless steel can be used but for hard materials tools made up from refractory materials are necessary. While joining of dissimilar metals tool offset is important factor because it avoid over heating of softer material. For this reason tool is kept on softer material side. The experiments are performed by varying levels of some important parameter like rotational speed and welding speed. The effect of work position and tool offset has been checked.

## V. EXPERIMENTAL PROCEDURE

The experiments are performed on aluminium 6061-T6 and 304L stainless steel plates having 4mm thickness, 50mm width and 125 mm length. The welding is performed on conventional milling machine with retrofitted friction stir welding setup. The machine is controlled by two motors only, namely, spindle motor and feed motor. The spindle motor is rated at 22 kW and the feed bed motor is rated at 2.2 kW. The main spindle motor provides the spindle rotation while the feed motor supplies power to all the three axis movements of the bed. The spindle speed is available from 30 to 675 rpm and feed rate is available from 12 to 430 mm/min. In order to perform welding operation special type of fixture required called backing plate which will hold the plates in butt joint form and will sustain the forces coming. The backing plate should be made up from such material that it can withstand high temperatures and also the welded joint should not stick to the plate. The backing plate used for experiments is made up of mild steel. The fixture is shown in fig. 2.

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 12, December 2017

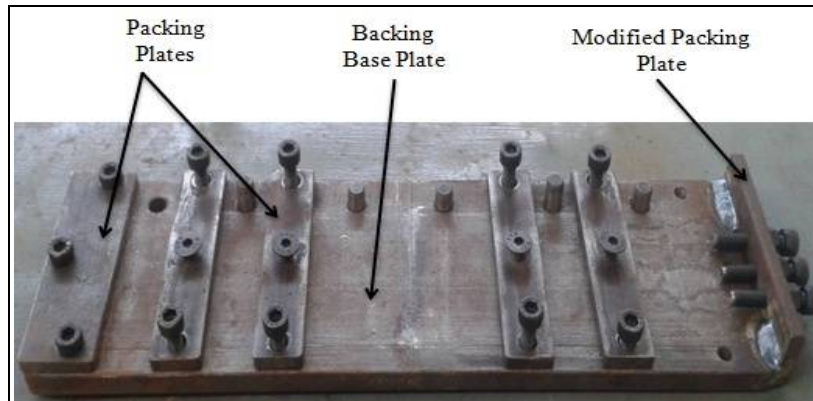











Figure 2: Fixture for welding process

The experiments are performed by varying the rotation speed between 290 to 675rpm, the welding speed between 12 to 40 mm/min. the experiments are performed by combination of levels of these two parameters randomly. The two tool materials used for experimental work are H13 tool steel and tungsten carbide. After welding the welded joints are visually observed and the observations are summarized in table 1.

Table 1: Experimental Details

Sr. No.	Rotational Speed (rpm)	Welding Speed (mm/min)	Tool offset	Tool material	Observation	Top view of joint
1	290	12	SS side	H13 Tool steel	Not Welded	
2	290	16	Al side	H13 Tool steel	Insufficient Heat Input	
3	380	16	No offset	H13 Tool steel	Tool Worn out	
4	675	16	Al side	H13 Tool steel	Excessive Heat Input	
5	675	40	Al side	Tungsten Carbide	Welded	
6	675	30	Al side	Tungsten Carbide	Welded	
7	510	16	Al side	Tungsten Carbide	Welded, Weld grooves	
8	510	30	Al side	Tungsten Carbide	Welded	
9	510	40	Al side	Tungsten Carbide	Voids	



# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 12, December 2017

## VI. RESULT AND DISCUSSION

From the experiments it is observed that the at 290 rpm and 12 mm/min welding speed that is at lower levels of parameter there is insufficient heat input so the welding is not done properly. At 40 mm/min welding speed the travelling of tool is comparatively fast so that voids are observed on weld. Also when the tool is on stainless steel side there is no welding obtained. When the tool steel is used, it observed that there is critical issue of tool wear and also heat input is low. The joints prepared by tungsten carbide gives satisfactory weld but also there is problems of voids. At higher levels of speed, there is excessive heat input which forms weld groves at the end of the weld on the other hand the higher level of welding speed causes voids on the weld bed. The axial force also plays an important role in this welding process. For the experimental work the axial force is kept constant at 2.5 KN. The low level of axial force can cause insufficient mechanical deformation of weld and the welding will not be done properly whereas higher axial force causes flashes to be formed on weld bed. From experiments it is also seen that the tool when kept on steel side worn out easily when it is on aluminium side overheating of aluminium is avoided.

## VII. CONCLUSIONS

The remarks concluded from the experiments performed on aluminium 66061-T6 and 304L stainless steel are given below:

- a) The tool which is used for experiments, which is made up of tool steel is failed due to insufficient hardness.
- b) While joining of steel and aluminium, steel should be always kept at advancing side and aluminium alloy on retreating side. Because the temperature on advancing side is higher than retreating side.
- c) In case of joining dissimilar metals having different melting temperatures tool should have offset towards low melting point material. So in this case tool should have offset towards aluminium side which will avoid overheating of aluminium.

## REFERENCES

- [1] R. Mishra and Z. Ma, "Friction stir welding and processing, Institute of Metal Research, Chinese Academy of Sciences", pp. 1-78, 2005.
- [2] B. R. Singh, "A Hand Book on Friction Stir Welding Lambert Academic Publishing", UK, 2012
- [3] Yazdipour and A. Heidarzadeh, "Effect of friction stir welding on microstructure and mechanical properties of dissimilar Al 5083-H321 and 316L stainless steel alloy joints", Journal of Alloys and Compounds, pp. 595-603, 2017.
- [4] A. N. Siddiquee, S. Pandey and N. Z. Khan, "Friction Stir Welding of austenitic stainless steel: a study on microstructure and effect of parameters on tensile strength", 4th International Conference on Materials Processing and Characterization, vol. 2, pp.1388-1397, 2015.
- [5] K. K. Ramachandran, N. Murugan and S. S. Kumar, "Effect of Tool Axis Offset and Geometry of Tool Pin Profile on the Characteristics of Friction Stir Welded Dissimilar Joints of Aluminium Alloy AA5052 and HSLA Steel", Materials Science & Engineering, vol. 639, pp. 219-233, 2015.
- [6] H. Uzun, C. D. Donne, A. Argagnotto, T. Ghidini and C. Gambaro, "Friction stir welding of dissimilar Al 6013-T4 to X5CrNi18-10 stainless steel", Materials and Design, vol. 26, pp. 41-46, 2005.
- [7] C. M. Chen, R. Kovacevic, "Joining of Al 6061 alloy to AISI 1018 steel by combined effects of fusion and solid state welding", International Journal of Machine Tools & Manufacture, vol. 44, pp. 1205-1214, 2004.
- [8] T. Kakiuchi, Y. Uematsu and K. Suzuki, "Evaluation of fatigue crack propagation in dissimilar Al/steel friction stir welds", 21st European Conference on Fracture, vol. 2, pp. 1007-1014, 2016.
- [9] X. Liu, S. Lan and J. Ni, "Analysis of process parameters effects on friction stir welding of dissimilar aluminum alloy to advanced high strength steel", Materials and Design, vol. 59, pp. 50-62, 2014.
- [10] T. Watanabe, H. Takayama and A. Yanagisawa, "Joining of aluminum alloy to steel by friction stir welding", Journal of Materials Processing Technology, vol. 178, pp. 342-349, 2006.
- [11] C. Meran and O.E. Canyurt, "Friction Stir Welding of austenitic stainless steels", Journal of Achievements in Materials and Manufacturing Engineering, vol.43, pp. 432-439.