Analysis of Influence of Tool Geometry on the Strength of Friction Stir Welded AA6061 Aluminum Alloy

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***Abstract*— Friction Stir Welding (FSW) was invented by Wayne Thomas at TWI (The Welding Institute), and the first patent applications were filed in the UK in December 1991 for butt and lap welding of metals and Plastics. FSW is a solid state welding process and joining similar or dissimilar metals in which the relative motion between the tool and the work piece produces heat which makes the material of two edges being joined by plastic atomic diffusion. This method relies on the direct conversion of mechanical energy to thermal energy to form the weld without the application of heat from conventional source. The rotational speed of the tools, the axial pressure, tool tilt angle and welding speed are the principal variables that are controlled in order to provide the necessary combination of heat and pressure to form the weld. This joining technique is energy efficient, environment friendly, and versatile. The advantages of this process include high reproducibility, short production time and low energy input. FSW process used for the aerospace, railway, land transportation, the construction industries. In this experimental work the effect of process parameters and tool geometry on the strength of AA 6061 Aluminum alloy is investigated. Weld strength is taken as response variable during the welding process. Experiments were performed using Taguchi method and analysis of experimental results is carried out by using MINITAB 16 software.**

***Keywords* – Friction stir welding, taguchi method, axial pressure, tool tilt angle and welding speed.**

I. INTRODUCTION

Friction stir welding (FSW) is a relatively new solid state welding process which is used for butt joints. FSW was invented by The Welding Institute, Cambridge, UK in 1991 and has emerged as a new process for welding of aluminum alloys. This process has made possible to weld a number of aluminum alloys that were previously not recommended (2000 series & copper containing 7000 series aluminum alloys) for welding. Because the material subjected to FSW does not melt and re-solidify, the resultant weld metal is free of porosity with lower distortion. An added the advantage that it is an environmentally friendly process. FSW is a solid state, localized thermo mechanical, joining process.

In FSW, a non-consumable rotating shouldered-pin-tool is plunged into the interface between two plates being welded, until the shoulder touches the surface of the base material, and then tool is transverse along the weld line. In FSW, frictional heat is generated by rubbing of tool shoulder and base material surface. During traversing, softened material from the leading edge moves to the trailing edge due to the tool rotation and the transverse movement of the tool, and this transferred material is consolidated in the trailing edge of the tool by the application of an axial force. FSW parameters are tool geometry, axial force, rotational speed, transverse speed and tool tilt angle.

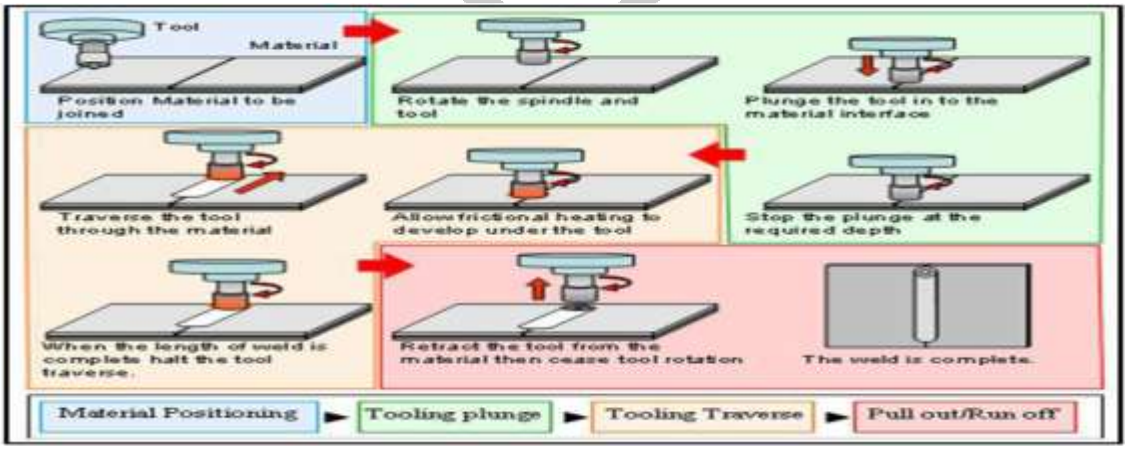

Fig. 1 Friction Stir Welding Process Flow chart

II ADVANTAGEs, DISADVANTAGES AND OBJECTIVES

ADVANTAGES

1. As a solid state process it can be applied to all the major aluminum alloys and avoids problems of hot cracking, porosity, element loss, etc. common to aluminum fusion welding processes.
2. Friction welding is environmentally friendly process as it does not generate fumes, gases or smoke.
3. No shielding gas or filler wire is required for aluminum alloy.
4. It is very flexible, being applied to joining in one, two and three dimensions, being applicable to butt, lap and spot weld geometries; welding can be conducted in any position.
5. Excellent mechanical properties, competing strongly with welds made by other processes.
6. Friction welding is consistent and repetitive process.
7. It consumes low energy and low welding stress.
8. It reduces maintenance cost.
9. It creates a narrow heat affected zone.

DISADVANTAGES

1. Not for higher strength materials.
2. Exit hole left when tool is withdrawn.
3. Large down forces required with heavy-duty clamping necessary to hold the plates together.
4. Less flexible than manual and arc processes (difficulties with thickness variations).
5. Often slower traverse rate than some fusion welding techniques, although this may be offset if fewer welding passes are required and non-linear welds.

OBJECTIVES OF STUDY

1. To optimize tool geometry required for FSW.
2. To enhance the sustainability of fixture for high tool rotational speed, weld speed and tool tilt angle.
3. To increase the strength of weld joint..
4. To optimize parameters (tool rotational speed, weld speed and tool tilt angle) by ANNOVA method.
5. Correlate the results of actual testing and the software results.

III WORK PIECE MATERIAL : - AA 6061-T6

Aluminum alloy 6061 is a medium strength alloy with excellent corrosion resistance. It has the highest strength of the 6000 series alloys. Alloy 6061 is known as a structural alloy. In plate form, 6061 is the alloy most commonly used for machining. As a relatively new alloy, the higher strength of 6061 has seen it replace 6082 in many applications. The addition of a large amount of manganese controls the grain structure which in turn results in a stronger alloy. It is difficult to produce thin walled, complicated extrusion shapes in alloy 6061. The extruded surface finish is not as smooth as other similar strength alloys in the 6000 series.

In this investigation, the base materials, Al 6061-T6, which is a precipitation hardened aluminum alloy widely used in aerospace applications due to its high strength was used. Table 1 shows the chemical composition of base metal AA 6061.

Table 1 Composition of aluminum alloy AA6061

Si	Fe	Cu	Mn	Mg	Cr	Ti	Zn
0.80	0.7	0.15	0.15	0.80	0.04	0.15	0.25

Tool Material: High Carbon High Chromium Steel (HCHCr)- It is found that the weld strength and weld quality is good for HCHCr steels compare to other steel materials. So it is decided to use tool made from HCHCr steel for further experimentation.

IV DESIGN OF EXPERIMENTS

Design of experiments is a method of designing experiments, in which only selected number of experiments are to be performed. For example if there are three parameters with three levels of each parameter, then the total number of experiments to be performed is $3^3 = 27$ experiments. But using Taguchi array method, only 9 experiments are required to be performed. On the basis of these 9 experiments, the significance and optimal levels of each parameter is obtained. So 9 experiments for each of the following cases are carried out,

Set 1 (S_1): Welds using Hexagonal pin profiled tool.
Set 2 (S_2): Welds using Heptagonal pin profiled tool.
Set 3 (S_3): Welds using combine Multiple-pass of the Hexagon and Heptagon Tool.

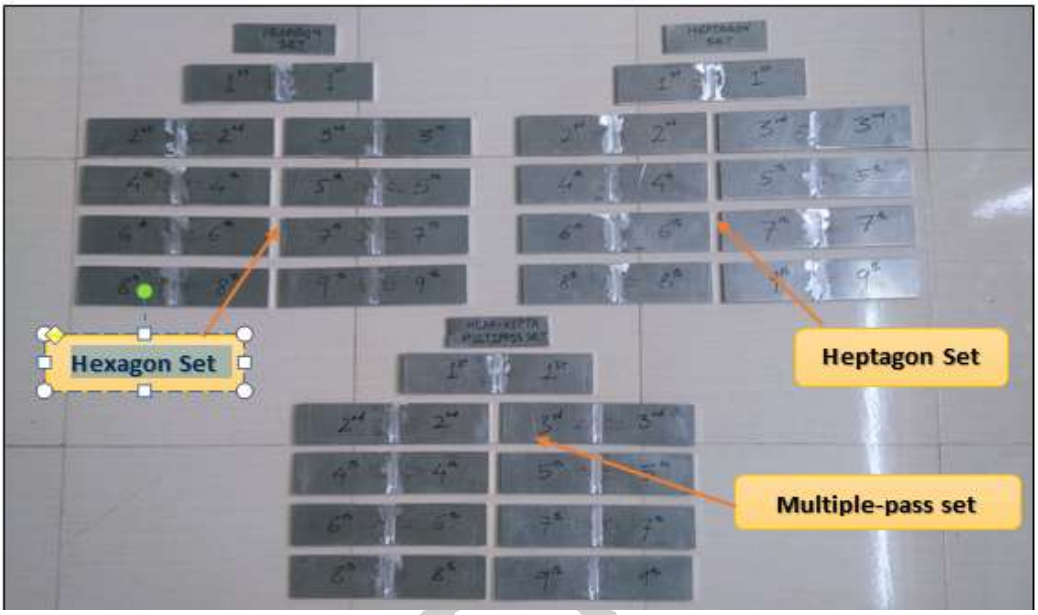

Fig. 2 All 27 (9 each case) specimens after completion of weld

V ANALYSIS OF VARIANCE (ANOVA) FOR RESPONSES

Analysis of variance (ANOVA) test was performed to identify the process parameters that are statistically significant. The purpose of the ANOVA test is to investigate the significance of the process parameters which affect the tensile strength of the FSW joints. The ANOVA results for all responses of means and S/N ratio are given in Tables 2, 3 and 4 respectively. In addition, the F-test named after Fisher can also be used to determine which process has a significant effect on tensile strength. Usually, the change of the process parameter has a significant effect on the quality characteristics, when F is large.

Table 2 ANOVA for Tensile Strength (S_1)

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Tool Rotation Speed(rpm)	2	29.723	29.723	14.862	137.76	0.007
Welding Speed (mm/min)	2	4.163	4.163	2.081	19.29	0.049
Tool Tilt Angle (°)	2	371.41	371.42	185.709	1721.48	0.001
Error	2	0.216	0.216	0.108		
Total	8	405.52				
S = 0.3284		R-Sq = 99.9%			R-Sq(adj) = 99.8%	

Table 3 ANOVA for Tensile Strength (S_2)

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Tool Rotation Speed(rpm)	2	29.191	29.191	14.596	49.90	0.020
Welding Speed (mm/min)	2	18.934	18.934	9.467	32.37	0.030
Tool Tilt Angle (°)	2	527.78	527.78	263.89	902.18	0.001
Error	2	0.585	0.585	0.293		
Total	8	576.48				
S = 0.5408		R-Sq = 99.9%			R-Sq(adj) = 99.6%	

Table 4 ANOVA for Tensile Strength (S_3)

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Tool Rotation Speed(rpm)	2	40.145	40.145	20.072	107.64	0.009
Welding Speed (mm/min)	2	26.070	26.070	13.035	69.90	0.014
Tool Tilt Angle (°)	2	478.93	478.92	239.46	1284.14	0.001
Error	2	0.373	0.373	0.186		
Total	8	545.52				
S = 0.4318		R-Sq = 99.9%			R-Sq(adj) = 99.7%	

The results of ANOVA indicate that the considered process parameters are highly significant factors affecting the responses of FSW joints in the order of Tool tilt angle, rotational speed and welding speed. Effects of interaction between process parameters are not significant. Main effect plot for tensile strength

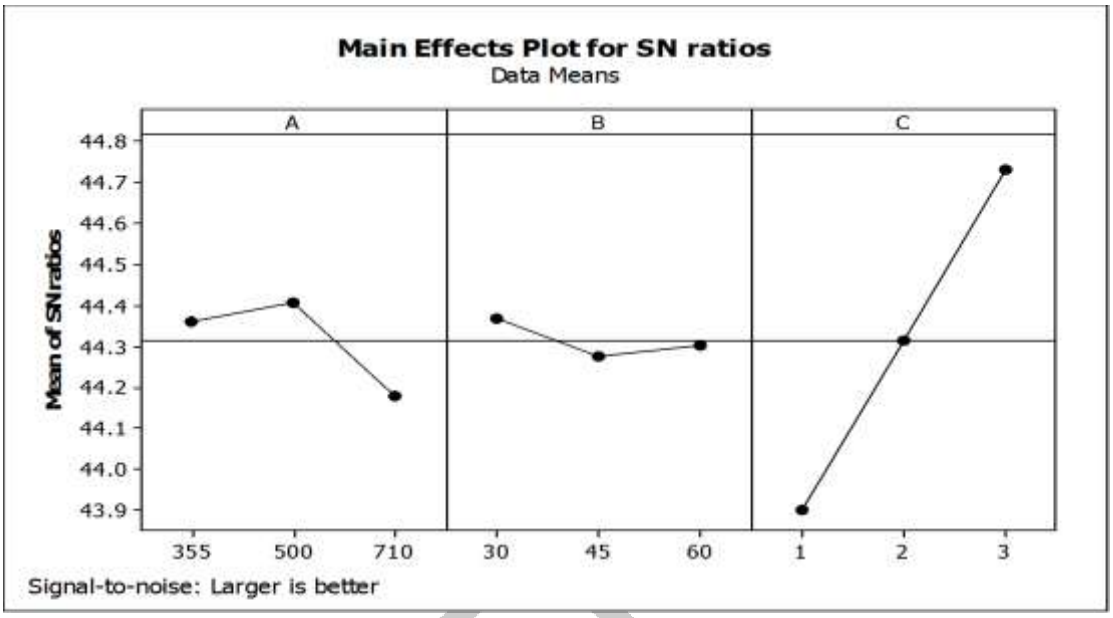

Fig. 3 Main Effects Plot of SN Ratios for Tensile Strength

CONCLUSION

1. Tensile strength of FSW is found to increase with increase in the value of tool tilt angle, since the problem of tunnel defect occurrence is less in 3° tilt angle.
2. The ultimate tensile strength of butt weld reaches to 68 to 72 % of the base metal ultimate tensile strength.
3. The Tensile strength is found to be maximum in case of Hexagon tool pin profile, i.e. 173.53 N/mm^2 followed by the Heptagon tool pin profile i.e. 167.50 N/mm^2.
4. Maximum Tensile strength of 165.46 N/mm^2 was achieved in case of combined Hexagon-Heptagon Multiple-pass FSW.
5. The strength obtained in case of Multiple-pass FSW process is found to decrease by 3.36% than the strength obtained in single pass experiment using hexagon tool.
6. For the given set of parameters, the optimum parameters were found to be tool rotation speed as 500 rpm, welding speed as 45mm/min and tool tilt angle of 3°.

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