Study on the Effect of Tool Material on Mechanical Properties and Microstructures of Friction Stir Welded AA 6061 Aluminum Alloy

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Abstract- In Friction Stir Welding frictional heat is generated by means of a non consumable rotating tool that forms plastic deformation at welding location. It leads to high joint strength, free from melt related defects, low distortion. Aluminum alloys are important for the fabrication of components and structures which require high strength, low weight. Here aluminum alloy 6061 is selected for the present study. Butt joints were made with friction stir welding; the tool materials used were SS 304, SS 316 and MS. Tensile strength of the produced joints were tested. Also the hardness and impact strength of joints were tested. Microstructures of weld zone of friction stir welds were analyzed using scanning electron microscope. Compositions of the welds were also found using scanning electron microscope. The results obtained revealed that the tool material SS316 gives high hardness, impact value and tensile strength when compared to SS304 and MS.

Keywords – FSW, process parameters, universal milling machine, tool material and profile

I. INTRODUCTION

In many industrial applications steels are readily replaced by nonferrous alloys, in most cases by aluminum alloys. With the need for fuel economy and weight saving, aluminum alloys are increasingly used in cars.Its two most important properties are density and thermal conductivity. Over the past 15 years the aluminum content of cars has increased from around 5% to 13% by both volume and weight. In engines ,they are used for pistons, cylinder heads and sumps**.** Even though the production of aluminum alloy is not complex, its joining may create problems. The present study focuses on the effect of tool material on mechanical properties and microstructures of friction stir welded AA6061 aluminum alloy. Friction stir welded joints of aluminum alloy 6061 were made using with different tools made of different materials, viz. SS 304, SS 316 and MS. The specimens of the weld joint were tested for tensile strength. Also hardness of weld nugget and HAZ were determined. Microstructures of the weld were analyzed with scanning electron microscope (SEM).

The study consists of seven sections. The review of some past works based on FSW and microstructures. The principles and operation of FSW are discussed. The microstructure developments in aluminum alloy friction stir welds are discussed. Also the experimental procedure of the study and the results of this work are presented and finally conclude the study.

II. EXPERIMENT PROCEDURE

2.1 Material selected:

The material selected for friction stir welding in the experiment investigation is Aluminum Alloy 6061.

2.1.A) The composition and mechanical properties of AA6061 aluminum alloys is given in Tables 1 and 2 respectively.

Element	Mn	Fe	Mg	Si	Cu	Zn	Ti	Cr	Al
% Composition	0.0 to 0.15	0.0 to 0.70	0.80 to 1.20	0.40 to 0.80	0.15 to 0.40	0.0 to 0.25	0.0 to 0.15	0.04 to 0.35	Balance

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

Property	Value
Proof Stress	270 MPa
Tensile Strength	310 MPa
Elongation A5	12 %
Shear Strength	190 MPa
Hardness Vickers	100 HV

Table 2:Mechanical properties of AA 6061

2.1. B) Main process parameters in friction stir welding & its effects are shown in the table:

2.2 Material selected for Tool:

The different tool materials selected for friction stir welding in the experiment investigation are Stainless Steel (SS 316), Stainless Steel (SS 304) and mild steel(MS).

Parameter	**Effects**
Rotation Speed	Friction heat, stirring, oxide layer breaking and mixing
Tilting angle	Appearance of the weld, thinning
Welding speed	Appearance, heat control
Down force	Friction heat

Table 3: Main process parameters in friction stir welding & its effects

Figure 1: FSW Welded joints using 3 different tools

Figure 2: The three different tools used for FSW (SS 316, SS 304, and MS)

III .DESIGN OF EXPERIMENTS

3.1 The details of the main process parameters selected for the experimental investigation is listed in the table shown below:

Process Parameter	**Symbols**	**unit**	**Different Levels**		
Rotation Speed	R	rpm	1000	1100	1645
Tool Material	M	-	MS	SS 304	SS316
Welding speed	W	mm/min	90	100	110
Down force	F	kN	Constant(10kN)	Constant(10kN)	Constant(10kN)

Table 4: Main process parameters in friction stir welding selected for the experimental investigation

Here, the various process parameters that affects the FSW is considered and the selected parameter along with their values are listed in the Table 4. The rotational speed of the spindle is taken as 1000, 1100 and 1645 respectively for the 3 different tool materials. The speed is selected on the basis of literature survey that the tool wear rate decreases as tool rotational speed increases and reaches a maximum. Further increase in tool rotational speed leads to increased wear rate. The tool rotation generates frictional heat as well as stirring and mixing of material around tool pin. Increase in frictional heat generation is observed with increase in tool rotational speed. A higher speed leads to higher heat generation than required. The welding speed also has the same effect as the tool rotational speeds. Proper equipment is essential for a successful welding. It requires equipment, which is designed for high welding forces without losing accuracy or repeatability of the process. The welding forces are for the same thickness increasing with increased alloying and with increased welding speed. As an example a 5 mm thick 6082 T6 butt joint can be welded at low speed with certain down force but the same welding at 6 m/min needs eight to ten times higher down force. So a welding force of 10kN is provided constantly for the welding tool with the help of a vertical milling machine.

IV. EXPERIMENTAL RESULTS

4.1 Brinell Hardness Test:

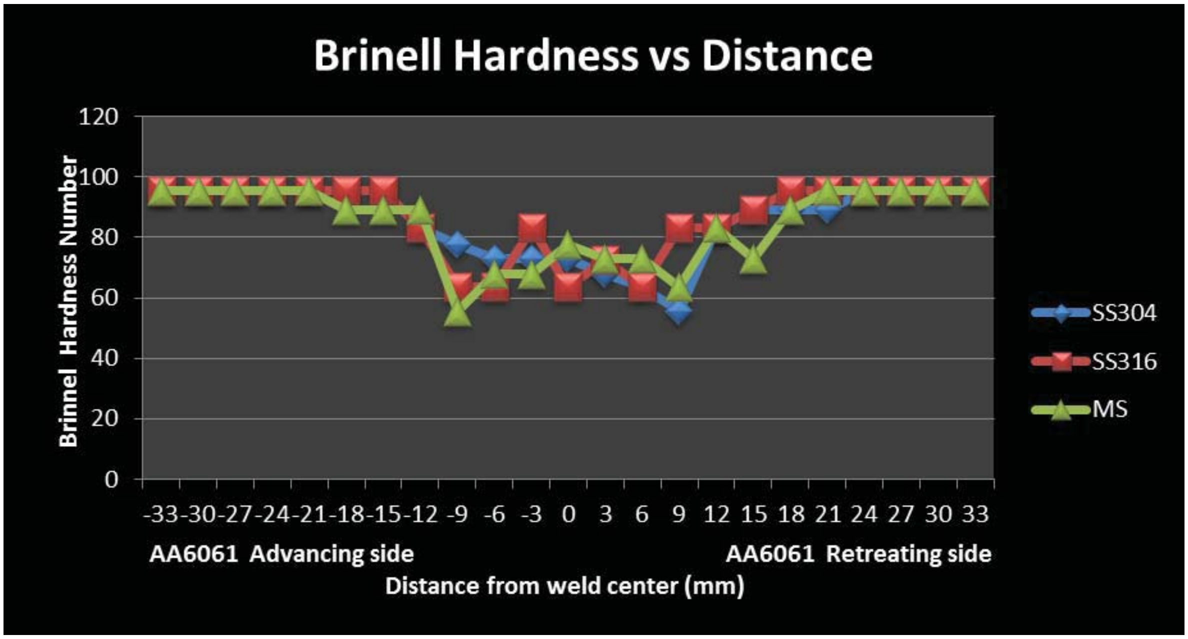
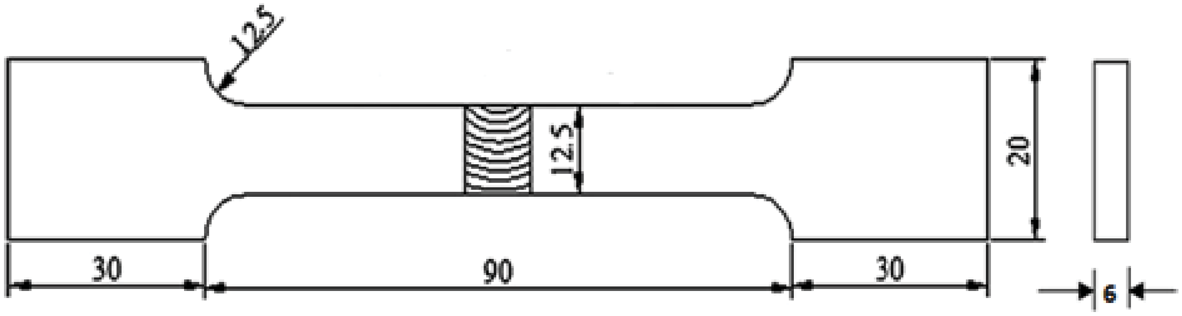


Figure 4.1: Hardness test result profile

4.2 Tensile Test:

4.2 A) The tensile test specimen made for the experimental investigation as per the ASTEM standards:



Dimensions of flat tensile specimen

ASTM E8M-04

All dimensions are in "mm"

Figure 4: Tensile test specimens of FSW Welded joints using 3 different tools

The Tensile test was conducted on Universal Testing Machine until the rupture of specimen. The specimen was prepared according to the ASTM E8M-04 standards, i.e., each specimen having 150mm length 20mm breadth and 6mm thickness. Tensile strength of the weld joint made by SS 316 tool was found to be greater. The greater tensile strength may be due to the formation of very fine grains in the weld nugget. The results obtained for tensile strength from SS 304, SS 316 and MS are tabulated in Table 6.5. The specimen for tensile testing is shown in Table 4.

Tool Material	**Tensile Strength of joints (MPa)**
SS 304	100
SS 316	123
MS	110

Table 4: Tensile test results of various specimens using 3different tools and varying parameters

V. CONCLUSIONS

Mechanical properties of FSW welded aluminum alloy 6061 change with various tool materials. Better properties were found while using SS316. The reduction in hardness of weld nugget was minimum in the case of SS316. Tensile strength of the joint made by SS316 found to be greater than the others. Impact values of the welded were found to be twice that of fusion welds. The impact strength of joint was found to be higher by 65% than the parent metal. It was found that SS 316 has a better impact value compared to SS 304. Microstructures of weld zone of friction stir welds as well as the compositions of the welds were also found using scanning electron microscope.

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