Studies on Optimization of Friction Stir Welding Process Parameters

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Abstract: Friction Stir Welding is a solid-state welding process 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. In this project an attempt is made to determine and evaluate the influence of the process parameters of FSW on the weldments. The tensile strength is considered for investigation by varying tool speed, welding speed and clamping position. Experiments were conducted on Aluminum alloy in a CNC Vertical Machining Centre. The output factors are measured in UTM. Results show strong relation and robust comparison between the weld mesh strength and process parameters. Hence FSW process variable data base is to be developed for wide variety of metals and alloys for selection of optimum process.

***Index Terms*–Friction Stir Welding (FSW), Tensile Strength, Hardness, Microstructure AA6061**

I. INTRODUCTION

This technique uses a non-consumable welding tool to generate frictional heating at the point of welding. It induces plastic deformation of work piece material while the material is in a solid phase, resulting in complex mixing across the joint. Being a solid-state process, this welding technique eliminates many of the defects associated with fusion welding techniques such as porosity, shrinkage, and solidification cracking. Friction Stir Welding used to weld nonferrous metals especially Aluminum Alloys. Later on, the process could extend its viability for other non-ferrous metals like copper, magnesium and brass and for welding of dissimilar material combinations. Now a days Metal Matrix Composites (MMC) materials are also welded with this process. In addition, friction stir welds can be accomplished in any position, as there is no weld pool. Apparently, friction stir welding is a valuable new technique for butt and lap joint welding of similar and dissimilar materials. Friction stir welding has lower environmental impact and cost benefits compared to fusion welding.

In Friction Stir Welding, a cylindrical shouldered tool, with a profiled threaded or unthreaded probe (nib or pin) is rotated at a constant speed and fed at a constant traverse rate into the joint line between two pieces of sheet or plate material, which are to be joined together. The parts to be welded should be clamped rigidly in a manner that prevents the abutting joint faces from being forced apart.

Pure aluminum is readily alloyed with many other metals to produce a wide range of mechanical properties. This means by alloying elements aluminum alloys are classified into two categories: non heat treatable and heat treatable.

1. First digit - principal alloying constituents
2. Second digit - variations of initial alloy
3. Third and fourth digits - individual alloy variations

1xxx- Pure A1 (99.00% or greater), 2xxx- Al-Cu alloys, 3xxx- Al-Mn alloys, 4xxx- Al-Si alloys, 5xxx- Al-Mg alloys, 6xxx- Al-Mg-Si alloys, 7xxx- Al-Zn alloys, 8xxx- A1+other elements, 9xxx- Unused series.

Mechanical Properties of AA6061 are:
Ultimate Tensile Strength: 328Mpa
Percentage of Elongation: 12% to 26%
Chemical Composition of AA6061

Table 1.1: Chemical Composition of AA6061

Mg	Mn	Fe	Si	Cu	Cr	Zn	Ti	Al
0.8-1.2	<=0.15	<=0.70	0.4-0.8	0.15-0.40	0.04-0.35	<=0.25	<=0.10	Balance

II OBJECTIVES

Based on the research gap, following objectives have been framed

- Optimization of friction stirs welding process parameters using Taguchi technique.
- To study the hardness characteristics
- To study the tensile characteristics
- To study microstructure characteristics

III EXPERIMENTAL WORK CARRIED OUT

OPTIMIZATION TECHNIQUES

In order to find the optimum tool rotation speed and welding speed that would yield the maximum tensile strength, the objective function is optimized using Taguchi optimization technique.

Taguchi method

Taguchi methods are statistical methods developed by Genichi Taguchi it is one of the most powerful DOE methods for analyzing of experiments. It can be used to improve the quality of manufactured goods, and more recently also applied to engineering biotechnology, marketing and advertising. Taguchi first applied his methods was Toyota. Since the late 1970s.

Product robustness, pioneered by Taguchi, uses experimental design to study the response surfaces associated with both the product means and variances to choose appropriate factor settings so that variance and bias are both small simultaneously.

Selection of process parameters

In the present study three process parameters such as Tool Rotation Speed, welding speed, load, which are mostly contribute to heat input and subsequently influence the mechanical properties of the welded joints were selected in two different levels.

Table 3.1 Process parameters of friction stir welding

Process parameters	**1**	**2**	**3**
Tool Rotating Speed (rpm)	200	400	600
Welding Speed (mm/min)	30	45	60
Load (KN)	2	4	6

Table 3.2 The Taguchi L9 design with three factors each three levels, along with the obtained response values from the corresponding runs.

SL NO	Tool rotating speed (rpm)	Welding speed (mm/min)	Load (KN)
1	200	30	2
2	200	45	4
3	200	60	6
4	400	30	4
5	400	45	6
6	400	60	2
7	600	30	6
8	600	45	2
9	600	60	4

FRICTION STIR WELDING OPERATION

In the friction stir welding, a non-consumable tool attached with a specially designed pin was inserted to the butting edges of the sheets to be joined. The tool shoulder had to touch the sheet surface. Under this condition the tool was rotated and traversed along the bond line. Thus, frictional heat was generated. Trial experiments were carried out according to the principles of the design of the experiments in order to determine the effect of the main process parameters.

Equipment

The process utilizes equipment that is similar to a machine tool, for which the welding conditions are preset. Therefore, the process can provide good reproducibility, and is not dependent on operator skill. The earliest feasibility studies were conducted on a modified, continuous-drive, friction-stir welding machine. Practical use necessitated increased welding capacity.

Welded samples

These undergiven specimens are the specimens which was friction welded and the material used is the AA6061 and two symmetric and identical pieces were kept aside in the form of a butt joint and were welded in the shown format. These speicimens were further cut into the format that is shown in the CAED drawing to perform the further operation

Figure 3.3: Welded Samples.

The following image depicts the cut part from the specimen with respect to the CAED Drawing with the specified dimensions.

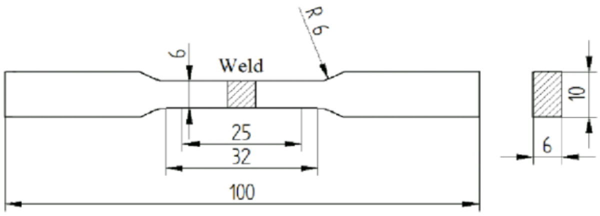

Figure 3.4: 2D Diagram of The Tensile Test Specimen.

Figure 3.5: Tensile Test Specimen.

Tensile Test

A tensile test, also known as a tension test, is one of the most fundamental and common types of mechanical testing. A tensile test applies tensile (pulling) force to a material and measures the specimen's response to the stress. By doing this, tensile tests determine how strong a material is and how much it can elongate

Ultimate Tensile Strength

One of the most important properties we can determine about a material is its ultimate tensile strength (UTS). This is the maximum stress that a specimen sustains during the test. The UTS may or may not equate to the specimen's strength at break, depending on whether the material is brittle, ductile, or exhibits properties of both. Sometimes a material may be ductile when tested in a lab, but, when placed in service and exposed to extreme cold temperatures, it may transition to brittle behavior.

Table 3.3 Properties of AA6061 before welding

UTS (MPa)	Hardness (Hv)
125	120

Microstructure

Microstructure is the very small-scale structure of a material, defined as the structure of a prepared surface of material as revealed by a microscope above 25× magnification. (or)"The arrangement of phases and defects within a material."

Grain size

Grain size (or particle size) is the diameter of individual grains of sediment.

Microstructure and Grain size Analysis.

Microstructure analysis is used among the various industries to find the structure of the material at various stages of testing. Thus the analysis explains about the structure of the materials. Generally, microstructure analysis is done by using the optical microscope but now a day there is development done with a digital analysis using Image progression methods.

Grain size analysisis a sediment logical analysis carried out in order to determine the size of the different particles that constitute a particular unconsolidated sedimentary deposit.

Vickers Hardness:

The basic principle, as with all common measures of hardness, is to observe a material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH).

the indenter shape should be capable of producing geometrically similar impressions, irrespective of size; the impression should have well-defined points of measurement; and the indenter should have high resistance to self-deformation

IV Results and Discussions

Tensile Test Results:

Sample 1:

The figure below shows the load v/s deflection curve

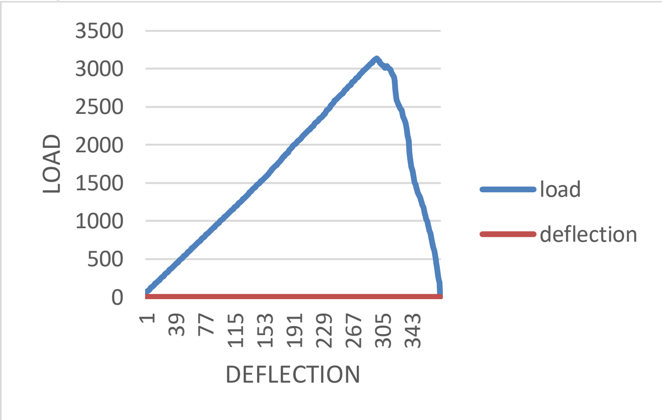

Figure 4.1: Load v/s Deflection curve

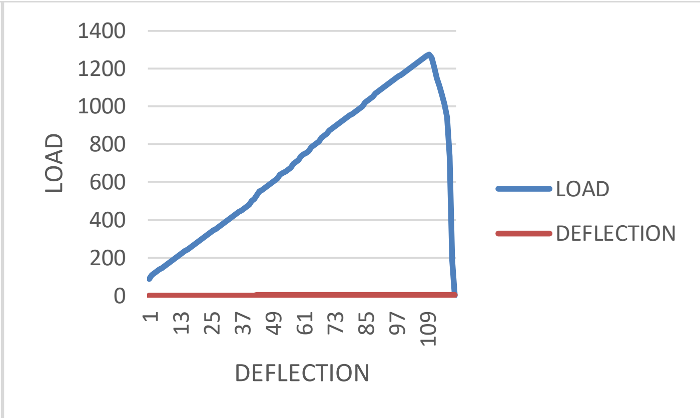

Figure 4.2: Load v/s Deflection curve

Table 4.1 The Taguchi L9 design with three factors-each three levels, along with the obtained response values from the corresponding runs.

Sl. No.	Tool rotating speed (rpm)	Welding speed (mm/min)	Load (kN)	UTS (MPa)	Joint efficiency= UTS after FSW/ UTS before FSW (%)
1	200	30	2	72	57.6
2	200	45	4	76	60.8
3	200	60	6	82	65.6
4	400	30	4	87	69.6
5	400	45	6	80	64
6	400	60	2	76	60.8
7	600	30	6	73	58.4
8	600	45	2	79	63.2
9	600	60	4	70	56

Microstructure and Grain size images:
Sample 1:

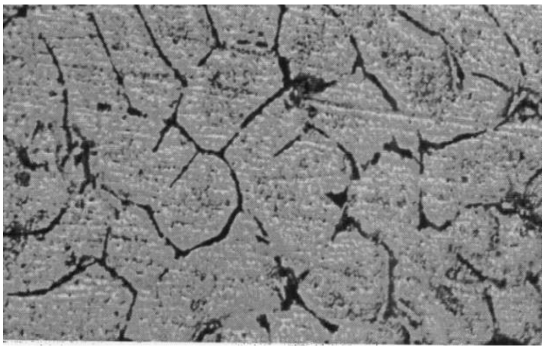
Figure 4.3: 100X Magnification (grain size)

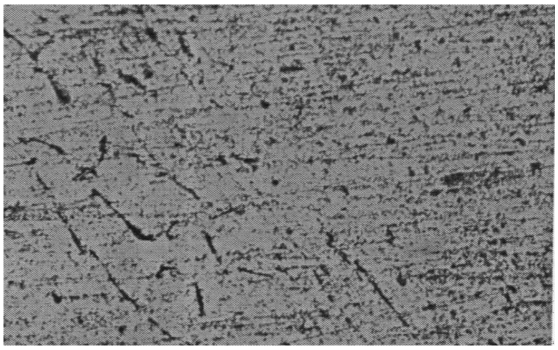
Figure 4.4: 200X Magnification (fusion zone)

Sample 2:

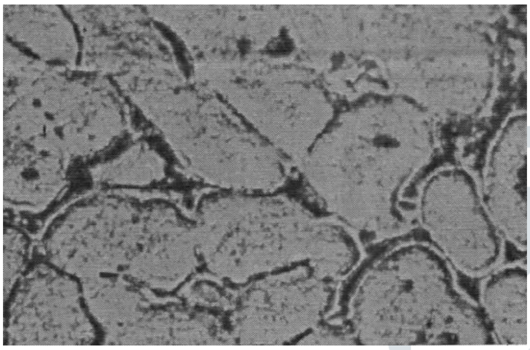
Figure 4.5 100x Magnification

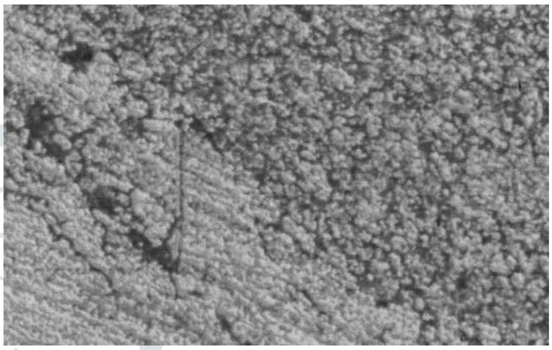
Figure 4.6 200x Magnification (fusion zone)

V Vickers Hardness Test

The microhardness tests were performed on a cross section perpendicular to the weld line, mid thickness across the weld zone and into the parent material, using a 2Kg load. For the analysis of micro structural changes due to the FSW process, the joints were cross-sectioned perpendicularly to the welding direction and etched with HF reagent. Hardness is the measure of resistance which material offers to change in shape.

Table 4.2: The Taguchi L9 design with three factors-each three levels, along with the obtained response values from the corresponding runs.

VI

Sl. No.	Tool rotating speed (rpm)	Welding speed (mm/min)	Load (kN)	Vickers Micro hardness test (HV)	Joint efficiency= Hardness after FSW/hardness before FSW (%)
1	200	30	2	97	80.83
2	200	45	4	100	83.33
3	200	60	6	103	85.83
4	400	30	4	107	89.16
5	400	45	6	110	91.66
6	400	60	2	107	89.16
7	600	30	6	103	85.83
8	600	45	2	109	90.83
9	600	60	4	100	83.33

Taguchi Analysis: UTS (Mpa) v/s A, B, C

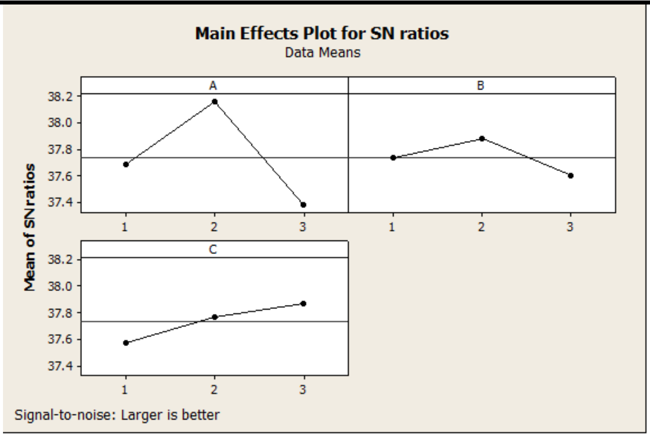

Figure 6.1: Plots for SN Ratios for Hardness.

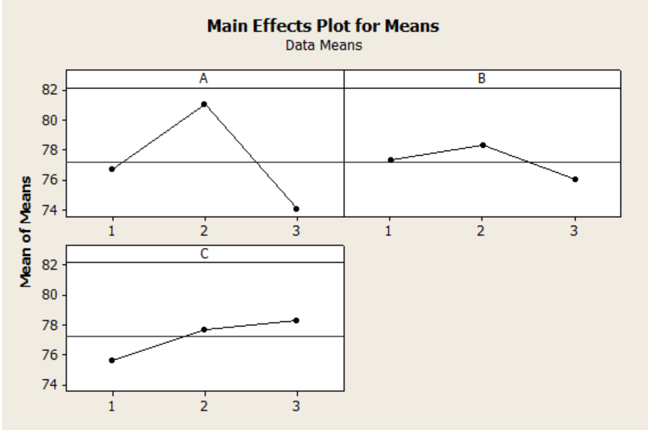

Figure 6.2: Plots for Means

In the current study, the S/N ratio is chosen to follow the principle of (larger is better) in order to maximize the response. Noise factors cannot be co4ntrolled during production or product use, but can be controlled during experimentation. In a Taguchi designed experiment, you manipulate noise factors to force variability to occur and from the results, identify optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. Higher values of the signal-to-noise ratio (S/N) identify control factor settings that minimize the effects of the noise factors. Taguchi experiments often use a 2-step optimization process.

Table 4.3 Taguchi L_9 design with three factors-each three levels, along with the obtained response values, S/N Ratios and Mean values from the corresponding runs.

A	B	C	UTS (Mpa)	S/N Ratio	Mean
1	1	1	72	37.1466	72
1	2	2	76	37.6163	76
1	3	3	82	38.2763	82
2	1	2	87	38.7904	87
2	2	3	80	38.0618	80
2	3	1	76	37.6163	76
3	1	3	73	37.2665	73
3	2	1	79	37.9525	79
3	3	2	70	36.9020	70

VII Taguchi Analysis: Vickers Microhardness (Hv) v/s A, B, C

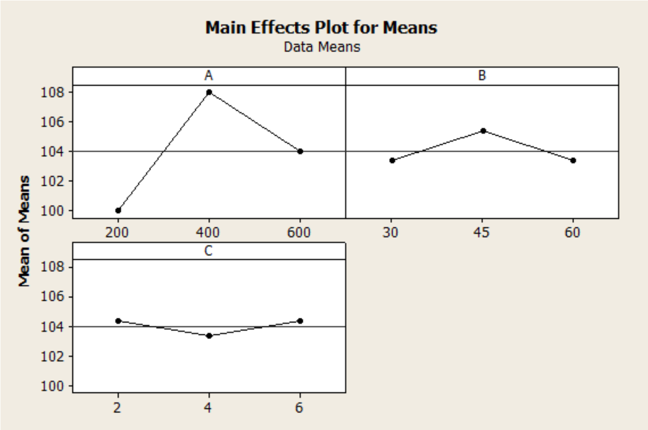

Figure 6.3: Plots for SN Ratios for Hardness.

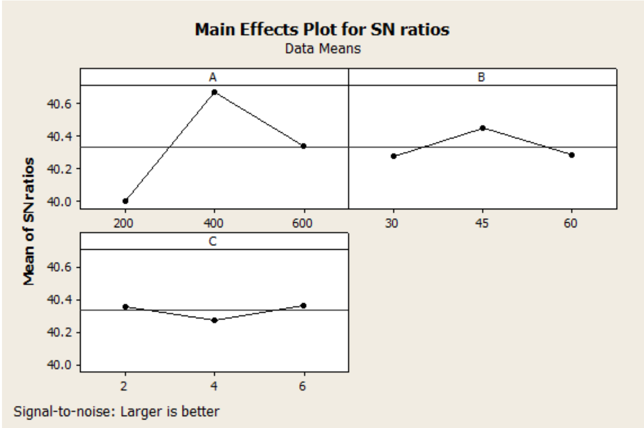

Figure 6.4: Plots for Means

Signal to noise ratios (S/N) for each control factor were calculated, in order to minimize the variances in hardness values. The signals indicate that the effect on the average responses and noises are calculated by the influence on the deviations from the average responses, which will disclose the sensitiveness of the experiment output to the noise factors. The appropriate S/N ratio must be chosen according to previous knowledge, expertise and understanding of the process. When the target is determined and there is static design, it is possible to choose the S/N ratio based on the goal of the design. In this study, the S/N ratio was chosen based on the criterion the-higher-the-better, to minimize the responses.

Table 5.4 Taguchi L_9 design with three factors-each three levels, along with the obtained response values, S/N Ratios and Mean values from the corresponding runs.

VIII CONCLUSIONS

A	B	C	Vickers Microhardness (Hv)	S/N Ratio	Mean
200	30	2	97	39.7354	97
200	45	4	100	40.0000	100
200	60	6	103	40.2567	103
400	30	4	110	40.8279	110
400	45	6	107	40.5877	107
400	60	2	107	40.5877	107
600	30	6	103	40.2567	103
600	45	2	109	`40.7485	109
600	60	4	100	40.0000	100

The experimental results indicated that the maximum tensile strength of the joints, which is about 75% that of the base plate, was obtained with a tool rotational speed of 950 rpm.

In general, it was found that higher rotational speed resulted in higher tensile strength.

This is due to the high local temperature achieved at higher spindle speeds leading to the formation of a large quantity of molten material leading to an efficient joint.

Also, from the bend test we conclude that the bend results obtained from welded specimen is close as that of parental metal.

IX References

- Thomas (1997) focuses on this study the relatively new joining technology, friction and surface oxide presents no difficulty to the process.
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- Rajkumar et al., (2011) explored the influence of process and tool parameters on tensile strength properties of AA6061 joints produced by friction stir welding.
- Krishnan (2002) carried out Post weld heat treatment (PWHT) of Friction Stir Welds (FSW) at solutioning temperatures of 520, 540, and 560ºC followed by ageing at 175ºC or 200ºC.
- Singh et al., (2011) reported the effect of post weld heat treatment (T6) on the microstructure and mechanical properties of friction stir welded 7039 aluminum alloy joints.
- Aladdin et al (2011) examined the effects of the welding parameters and the post weld aging treatment of FS welded AA6063-T4 at various tool rotations (800, 1120, and 1600 rpm) and welding speeds (200 and 315 mm/min) using a special tool with a height-adjustable and right-hand threaded pin.