Optimization of Mechanical Properties in Friction Stir Welding by using Taguchi Method

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***Abstract*-Friction Stir Welding (FSW) is a solid –state process leads to several advantages over fusion welding methods. This process uses a non-consumable tool to generate frictional heat required to performance sound joint. The welding process involves a rotating tool with a shoulder and a pin that generates heat and facilitates the flow of the softened solid alloy behind the tool where the welded joint forms.**

The welding parameters such as rotational speed, transverse speed, axial force, tool tilt angle, etc. and tool pin profiles play a major role in deciding the joint properties. In the past, very little work had been done on straight cylindrical tool with different shoulder diameters. So in this work, the two pieces of similar aluminum alloy will be welded by using a straight cylindrical tool with different shoulder diameter on vertical milling machine by means of friction, with varying feed rate and varying the speed of the tool at three different levels.

The Taguchi Method will be used to find the combination of the three welding parameters. In this work three parameters will be taken and L9 orthogonal array will be selected to optimize parameters for strength of the welded joint. After the welding, the strength of the joints by applying tensile load, hardness and elongation will be checked on the welded pieces to determine optimum speed and optimum feed rate at suitable tool shoulder diameter.

I. INTRODUCTION

Friction stir welding (FSW) has become a technology of widespread interest because of its numerous advantages, most important of which is its ability to weld otherwise unweldable alloys. Although originally perceived as a technology for joining conventionally unweldable materials, mostly alloys of aluminum, it is currently being investigated for a number of other materials including ferrous alloys like stainless steels. One of the reasons why academic and research interests are being focused on the use of FSW for these materials is its capability of producing high quality solid-state joints. Due to the absence of melting, the temperatures involved are considerably lower than those encountered in fusion welding techniques.[1] FSW as an extrusion process as well, saying that for each rotation of the tool, a cylindrical section of material is extruded around the probe and a banded structure within the weld results. He asserted that these bands, or "onion rings", which can appear as concentric rings or semicircles depending on which cut plane they are viewed from, result from oxidation on the surface of each semi-cylinder [2]dissimilar friction stir welding between 5052 Al alloy and AZ31 Mg alloy with the plate thickness of 6 mm. Sound weld was obtained at rotation speed of 600 rpm/min and welding speed of 40 mm/min. Compared with the base materials, the microstructure of the stir zone is greatly refined. Complex flow pattern characterized by intercalation lamellae is formed in the stir zone. Micro hardness measurement of the dissimilar welds presents an uneven distribution due to the complicated microstructure of the weld, and the maximum value of micro hardness in the stir zone is twice higher than that of the base materials. The tensile fracture position locates at the advancing side (aluminium side), where the hardness distribution of weld shows a sharp decrease from the stir zone to 5052 base material.[3]Friction stir welding (FSW), a solid state joining Technique invented in 1991 by The Welding Institute (TWI) and is one of the most significant developments in joining technology over the last half century. FSW involves the joining of metals without fusion or filler materials and is derived from conventional friction welding. Nowadays, AA6061 is one of the primary choices for light plane skin, which needs moderately high yield strength and hardness.[4]designTool design is one of the most important factors to considerwhen designing a FSW joining process. The tool must perform manyfunctions, including generating heat, promoting mixing, break-ing up the joint line, dispersing oxide layers, creating forgingpressure, containing material within the joint, therebypreventingsurface weld flash, and preventing the formation (or minimizing theimpact) of defects such as wormholes, sheet-thinning, or hookingdefects. Additionally, tool geometry must often facilitate a stableforce or torque control scheme and be compatible with a range ofplungedepths.The earliest tool designs consisted of a flat, featureless shouldersand cylindrical, perhaps threaded, probes.[5]

II.EXPERIMENTAL SET UP

The experimental setup used for conducting the experiments is given below:

1. *Friction stir welding on vertical milling machine*

The vertical head clamps the vertical sliding surface of the milling machine motor is mounted to the shoulder of the head and drives the vertical spindle via a Poly-V belt and drive system. The specification of the milling machine shown in the table1

Table 1: Specifications of Milling Machine

Specifications	Values
Manufacturer	PACMILL (semiautomatic)
Spindle Position	Vertical
RPM range	4650 R.P.M
Diameter of Tool Holder	17 mm
Motor	3 hp, 1430 rpm
Longitudinal Transverse speed Range	12-900 mm/min

2.Welding Tool

During the welding, the Straight Cylindrical shape tool is used and the material of the tool is High Carbon Steel. The dimensions of tool are shown in table.2.

Table 2: Tool Dimensions

Specifications	Values
Length of Tool	70 mm
Tool Shoulder Diameter	17 mm
Pin Diameter	6 mm
Pin Length For Single Pass	5.8 mm
Pin Length For Double Pass	3 mm

3. Work Piece Material

Aluminum 6061 is used as the work piece material for carrying out the experimentation to optimize the Tensile strength. The plates used are of thickness 6mm and length & breadth of 50mm.

4. Working Level Of Process Parameters

Experiments are performed to find the working levels of parameters. The levels are observed in experiments are shown in the Table.3.

Table: 3. Process Parameters

Level	Tool Speed (rpm)	Feed Rate (mm/min)	ShoulderDia. (mm)
1	1950	20	16
2	3080	25	18
3	4600	30	20

5. Design Of Experiment

Taguchi's designs aimed to allow greater understanding of variation than did many of the traditional designs. Taguchi contended that conventional sampling is inadequate here as there is no way of obtaining a random sample of future conditions. Taguchi proposed extending each experiment with an "outer array" or orthogonal array should simulate the random environment in which the experiment would function. The design of experiment is shown in Table.4

Table 4: Design of Experiment

Sr. No.	Tool Speed(rpm)	Feed Rate(mm/min)	Shoulder Dia. (mm)
1	1950	20	16
2	1950	25	18
3	1950	30	20
4	3080	20	18
5	3080	25	20
6	3080	30	16
7	4600	20	20
8	4600	25	16
9	4600	30	18

6. Ultimate Tensile Strength

Then tensile testing has been done on UTM until fracture of specimen and calculates the Ultimate tensile strength and elongation for all specimens.

7. Rockwell Hardness Test

The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by preload. There are different Rockwell scales, which are denoted by a single letter, that use different loads or indenters. The scale used in this experiment is *B Scale* that uses load100 kgf and has 1⁄16-inch-diameter (1.588 mm) steel sphere indenter and is mainly used for testing Aluminium, brass, and soft steels. Thus the hardness obtained is called HRB.

III. RESULTS AND DISCUSSIONS

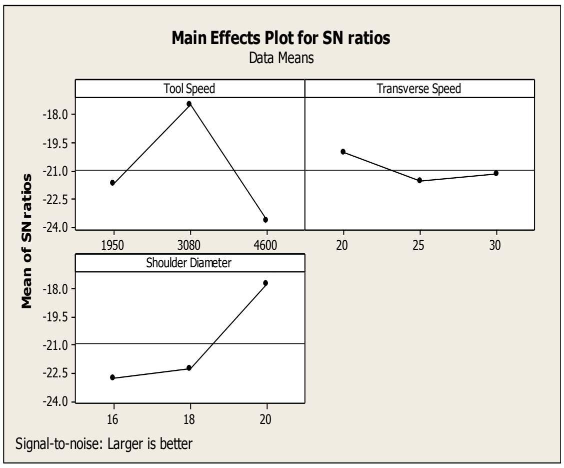
Optimizing of the ultimate tensile strength

In the first run nine experiments are performed and tensile strength is calculated on the universal testing machine as shown in the table: 5and Fig .1

Table5: Tensilestrengthof the Specimens for Single Sided Joint

Speed (r.p.m)	Spl No.	Feed (mm /min.)	Shoulder Dia.(mm)	Area (mm)	Load (KN)	Tensile strength (KN/mm^2)
1950	S1	20	16	150	9	0.07
	S2	25	18	150	11.2	0.07
	S3	30	20	150	18.5	0.120
3080	S4	20	18	150	20	0.130
	S5	25	20	150	23.7	0.15
	S6	30	16	150	17.5	0.116
4600	S7	20	20	150	17.2	0.116
	S8	25	16	150	7.8	0.050
	S9	30	18	150	7	0.050

Fig.1: Change in tensile strength with varying speed, feed and shoulder dia.



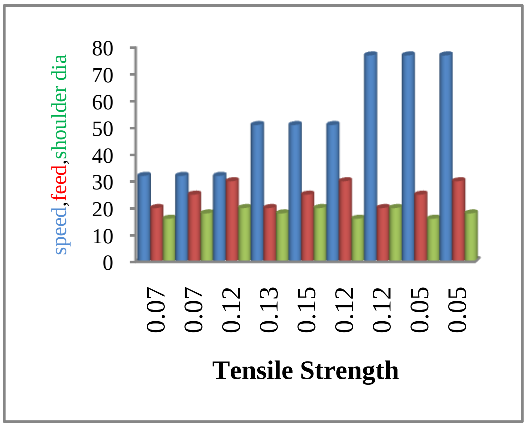


Fig. 2: Effect of Welding Parameters on Tensile Strength for S/N Ratio

4.1.1 Tool Speed

The effect of tool speed on the Tensile strength values is shown in Fig.2 for S/N ratio. Its effect is increasing with increase in tool speed up to3080 RPM. So the optimum tool speed is **level 2 i.e. 3080 RPM.**

4.1.2 Feed Rate

The effect of feed rate on the tensile strength values are shown in Fig.2 for S/N ratio. Its effect is decreasing with increase in feed rate. So the optimum feed rate is **level 1 i.e. 20mm/min.**

4.1.3 Shoulder Diameter

The effect of parameter shoulder diameter on the tensile strength values is shown in Fig. 2 for S/N ratio. Its effect is increasing with increase in shoulder diameter. So the optimum depth of cut is **level 3 i.e. 20 mm.**

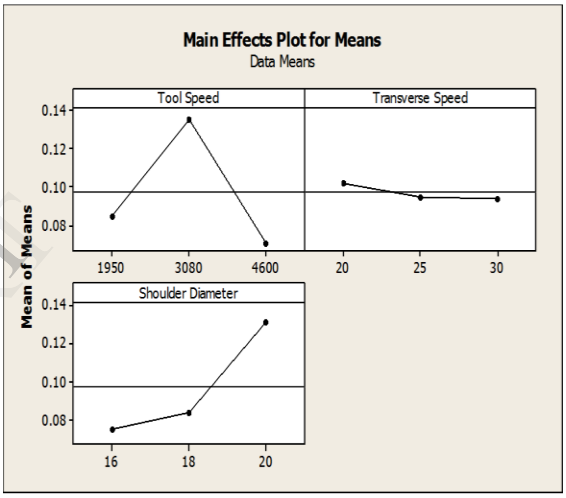


Fig. 3: Effect of Welding Parameters on Tensile Strength for Means

4.2 DISCUSSION

Taguchi method stresses the importance of studying the response variation using the signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The Tensile strength was considered as the quality characteristic with the concept of "the larger-the-better".

The S/N ratio for the larger-the-better is:

$$S/N = -10 log_{10}\{\frac{1}{n}\sum\frac{1}{y^2}\}$$

Where n is the number of measurements in a trial/row, in this case, n=1 and y is the measured value in a run/row. The S/N ratio values are calculated by taking into consideration Eqn. with the help of software Minitab 15.

Finally we got the optimum value of parameters of welding process for maximum tensile strength which is given in Table 6

Table 6: Optimum Value of Parameter According to S/N Ratio

Tool Speed (RPM)	Feed Rate (mm/min)	Shoulder Dia.(mm)	Tensile strength (KN/mm^2)	Elongation (%age)
3080	20	20	0.164	16

The Fig.4 Shown the comparison between the optimum value of tensile strength according to S/N ratio and the value of tensile strength obtained from the L9 orthogonal array.

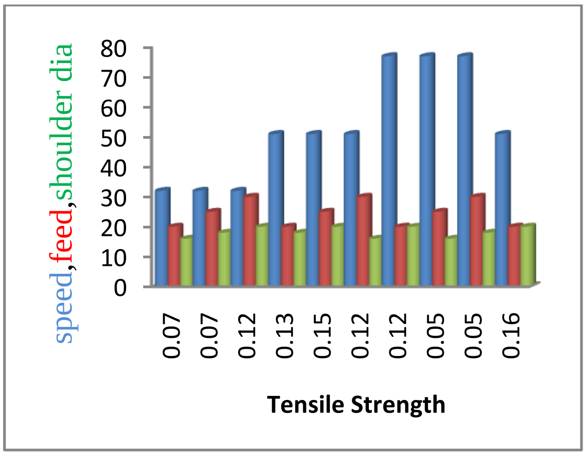


Fig. 4: Comparison b/w change in tensile strength & its optimum value acc. To S/N ratio

The Fig.5 Shown the comparison between the optimum value of elongation % according to S/N ratio and the value of elongation % obtained from the L9 orthogonal array.

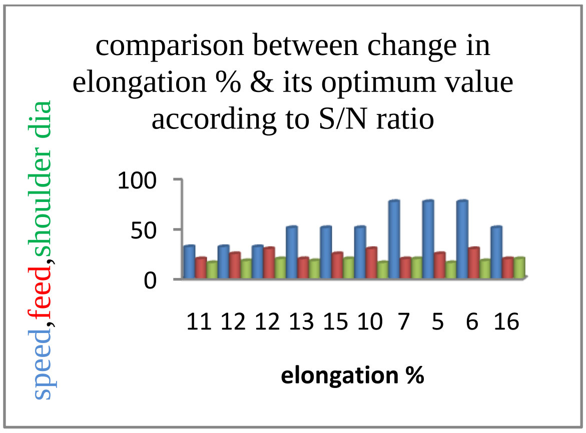


Fig. 5 : Comparison b/w change in elongation % & its optimum value acc. To S/N ratio

4.3 Rockwell Hardness Test

The Fig.6 and table7 shown surface joint hardness (HRB) for nine specimens at different parameters such as feed rate, transverse speed and shoulder diameters. The graph shown the maximum and minimum value of hardness at welding joint on different parameters such as feed rate, transverse speed and shoulder diameters.

Table 7: Rockwell hardness No. of the Specimens for Single Sided Joint

Speed (r.p.m)	Sml No.	Feed (mm/min.)	Shoulder Dia.(mm)	Rockwell hardness No. (B-Scale)
1950	S1	20	16	30
	S2	25	18	24
	S3	30	20	48
3080	S4	20	18	52
	S5	25	20	55
	S6	30	16	46
4600	S7	20	20	46
	S8	25	16	28
	S9	30	18	30

Fig. 6: Change in hardness with varying speed, feed and dia.

IV. CONCLUSION

The For solving welding optimization problems, various conventional techniques had been used so far, but they are not robust and have problems when applied to the welding process, which involves a number of variables and constraints. To overcome the above problems, Taguchi method is used in this work. Since Taguchi method is experimental method it is realistic in nature. The present study is carried out to study the effect of input parameters on the tensile strength. The following conclusions have been drawn from the study:

- The Tensile strength is mainly affected by Tool speed and beside it shoulder diameter & feed rate also affect to some extent.
- The Parameters considered in the experiments are optimized to attain maximum Tensile Strength. The best setting of input process parameters for maximum Tensile Strength is Tool speed-3080 rpm, feedrate-20 mm/min, and Shoulder diameter-20 mm.
- The hardness is mainly affected by Tool speed and beside it shoulder diameter & feed rate also affect to some extent.
- The graph shown the maximum and minimum value of hardness at welding joint on different parameters such as feed rate, transverse speed and shoulder diameters.

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