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Evaluate the Effect of Various Parameters of Friction Stir Welding on the Hardness of Welded Joint and variation of Temperature at different parameters

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Abstract

A Friction stir welding is also known as solid-state joining process where heat is generated with a third body tool for the joining of two metal surfaces. The main objective of this work is to determine the effects of mentioned parameters used in friction stir welding on the temperature gain or heat generated and to get the various optimal sets of the process parameters so that the response can be optimized. In present work the effects of mentioned process parameters of Friction stir welding such as tool rotation speed, tool feed rate and the tool shoulder diameter have been investigated to find effect on heat generation or temperature gain which is important factor for joining of two metals. Temperature is measured using an infrared thermometer and heat generated is a direct function of temperature. Hardness of the welded surface important role in many applications of the friction welded joint. Using a Vickers Hardness test the hardness is measured. Experiments of present work were designed by using Taguchi methodology. An Orthogonal Array L9 was used and results obtained by the experimentation were analyzed by using MINITAB software analytically as well as graphically.

Keywords: *FSS, Charpy test, Impact Strength, Taguchi Analysis, Welding, Welding Joint*

1. Introduction

It is also known as solid-state joining process which uses a third body tool for joining the two metal surfaces. Heat is obtained between tool and the material to be welded which makes a very soft region near the FSW tool. It mechanically intermixes two metal pieces at the place of the joint, then the softened metal at elevated temperature can be joined with a mechanical pressure applied by the tool shoulder, it is much like joining clay. It is basically used on aluminum and it is most often used on extruded aluminum also called non-treatable alloys and on few structures, needs superior weld strength without post weld heat treatment.

A rotated non-consumable cylindrical tool having shoulder rotated at constant speed with a profiled probe which is transversely fed at constant rate of a butt joint between two clamped pieces of butted material. The probe of the tool is slightly shorter than weld depth required with tool shoulder that rides a top the work surface. Frictional heat is generated between the wear-resistant welding components and the work pieces. Heat generated during the mechanical mixing process cause the stirred materials to soften without melting. As pin is moves in forward direction, a special profiled tool on the leading face forces the plasticized material to rear whereas clamping force makes a forged consolidation of weld.

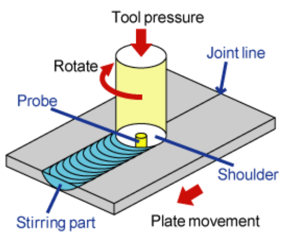

Figure: 1 FSW Welding

2. Literature Review

The Friction stir welding was first invented in December 1991 by The Welding Institute (TWI). TWI has filed successfully the patents in the Europe, Japan, and Australia. TWI established TWI Group-Sponsored Project 5651. The project was conducted in three phases. Phase I proved this to be a realistic and practical technique of welding, while at the same time addressing the welding of 6000 series aluminum alloys. Phase II has successfully examined the aerospace welding and another on ship aluminum alloys of 2000 series and 5000 series, respectively. Metallurgical characteristics, Process

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parameter tolerances, and mechanical properties for these materials were also established. Phase III was developed for industrialization of FSW.

Pasquale Cavaliere *et al*. (2013) [7] experimentally studied the various effect of processing parameters on the tensile strength, fatigue and the crack behavior of aluminum alloys. It is concluded that parameters affect defects, heat input, microstructure and residual stresses. Also, the welding force decrease with increase in the revolutionary pitch and the welding force increases with decreasing in tool tilt angle.

K. Kimapong *et al*. (2004) [1] performed friction stir welding on an aluminum alloy with magnesium to steel. The effects of rotation speed, pin offset and the structure of a joint were investigated. It is concluded from the experiment that lowering the rotation speed give rise to an insufficient increase in temperature at weld thus the pin wore out in a small time. At a high rotation speed, the temperature increase was so much that the magnesium in the Aluminium alloy oxidized and gives an unsound joint.

Vukcevic Milan *et al*. (2009) [3] The research successfully performed the joining of aluminum alloy 6082-T6 using FSW. experiment has established the shoulder diameter; pin diameter and tilt angle of the pin have large effect on welding speed and rotation speed. The paper presents a measurement of force which is defined by the components in x, y and z direction and mechanical tests were performed - determination of the tensile strength of welded joints and the tensile strength of welding zone.

G. H. Payganeh *et al*. (2011) [2] pp composite plates with 30% GF were welded with this process. The effects of tool geometry were first investigated on tensile strength and weld appearance experimentally. It is found that the tensile strength of specimens was 9 MPa which is found almost 25% of the base plate.

Atul Suri *et al*. (2014) [8] compares specimen of commercial aluminum for butt welded joint produced by FSW process using a special tool It is concluded that the surface appearance and the material accumulation on the advanced side increases with decrease of rotational speed at a constant feed rate. At higher tool, rotational speeds due to excessive melting of the base metal in the weld nugget the surface finish starts deteriorating using standard tool where as improved tool produces better surface.

M. De Giorgi1, A. Scialpi, F.W. Panella1 and L.A.C. De Filippis *et al*. (2009) [4] has analyzed the FSW joints to evaluate the influence of three shoulder geometries on the weld performance. At first, the produced joints were characterized by a microstructural and a macroscopic analysis. A light influence was observed on the nugget grain dimensions due to the different heat input produced by the studied shoulders. The TF shoulder produced the coarsest recrystallized grains because of the higher peak temperature reached in the thermal cycle. The microhardness values in the NZ were coherent with the grain size; the highest value of nugget microhardness was due to a finest structure.

3. Experimental Methodologies

A well-known technique i.e. Taguchi method provides an efficient and systematic methodology for optimization of process parameters and this proves to be a powerful tool for the design of experiment. The gained wide popularity in the field of engineering and the scientific community. This is methodology for obtaining the parameters which are minimally sensitive for the various causes of variation and those produce high-quality products with low development. Orthogonal array and Signal to noise ratio are two major tools used in robust design.

The S/N ratio characteristics can be divided into three categories when the characteristic is continuous.

- Nominal is the best
- Smaller the better
- Larger is better characteristics.

For the maximum material removal rate, the solution is "Larger is better" and S/N ratio is determined according to the following equation:

S/N = -10 *log(Σ(1/Y2)/n)

Where, S/N = Signal to Noise Ratio,
n = No. of taken Measurements, y = Value Measured

The effects of each factor can be easily and more clearly presented with the help of response graphs. Using S/N response graphs optimal cutting conditions of control factors can be very easily evaluated. Parameters selection and design is the essential step in the Taguchi method to get the reliable results without experimental costs increased.

In comparison to above method the Taguchi orthogonal array make list of nine experiments in a order which cover all factors. Those nine experiments will give 99.96% accurate result. By using this method number of experiments reduced to 9 instead of 27 with almost same accuracy.

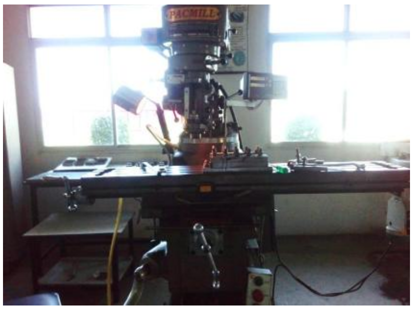

Figure 2 Vertical Milling Machine with some special Attachments and modifications

The toll specially designed made of High Speed 13 is used to for the stirring purpose. Butt joint is made using material Aluminium 6063 as working material with three parameters such as tool rotating speed, tool feed rate and the shoulder diameter of the tool. The various rotating speed levels are 600, 1200, 1800 rpm. Also, the various levels of feed rate are 25, 35, 45 mm/min also the levels of shoulder diameter are 12, 15, 18 mm

Hardness

The hardness is defined as "Resistance of the metal to the plastic deformation, usually due to indentation. These terms may also refer to the stiffness, or to the resistance to scratching, also to the abrasion, or to the cutting. It is the metal property which gives it ability to resist deformation such as bending, braking when the load is applied. Greater the hardness of the metal, the greater resistance to deformation.

Infrared Thermometer

The device also called laser thermometers that measures temperature from a distinct point by the thermal radiation emitted by object being measured. These are temperature guns, to describe the its ability to measure the temperature from a distance. With the amount of infrared energy emitted by the object and its emissivity, temperature of the object can often be determined.

Figure 3 Infrared Thermometer

Rockwell Hardness Test

Rockwell Hardness tests include forcing an indenter such as diamond or ball into the surface of a test piece in two steps. In first i.e. preliminary test force and thereafter with some additional force and then measuring depth of a indentation after removal of additional test force.

Brinell test consists of forcing a hardened ball into surface of a test piece with a specified test-force and measuring the diameter of indentation for evaluation of Brinell hardness number.

Figure 4 Rockwell Hardness Test Apparatus

Work Piece Material

In this work Aluminium 6063 is used for the experimentation. Aluminium 6063 have fare tensile strength, impact strength and low fusion temperature. Good thermal conductivity and lower fusion temperature making it suitable for friction stir welding process. It have many application for . In this work H13 tool steel plate of 55 mm x 10 mm x 3 mm is used for Experimentation.

Figure 5 Workpiece

Experimental Procedure

The experiments were carried out on a Rockwell Hardness Test machine having some special attachments and modifications of Technology Education & Research Integrated Institution, Kurukshetra India. The tool having indentation ball of diameter 1.588 mm 0r 1/16 inch is used to make indentation on the aluminium surface. Various experiments were made at different levels of parameters. Also an infrared thermometer is used to measure the temperature of welded bead during the process. After the observation from experimentation and Rockwell Hardness Test for hardness, the data thus obtained is used in MINITAB software for the calculations of S/N ratio and mean.

4. Result and Analysis

Table 1 Observation table Rockwell Hardness Test for Hardness

Expt. No.	Tool Rotation(RPM)	Feed Rate(mm/min)	Shoulder Diameter(mm)	Hardness B Scale	Temperature Calcious
1	600	25	12	85.75	192
2	600	35	15	92.5	114
3	600	45	18	80	193
4	1200	25	15	94.75	128
5	1200	35	18	74.25	205
6	1200	45	12	92.25	154
7	1800	25	18	89	163
8	1800	35	12	92.5	189
9	1800	45	15	91.25	136

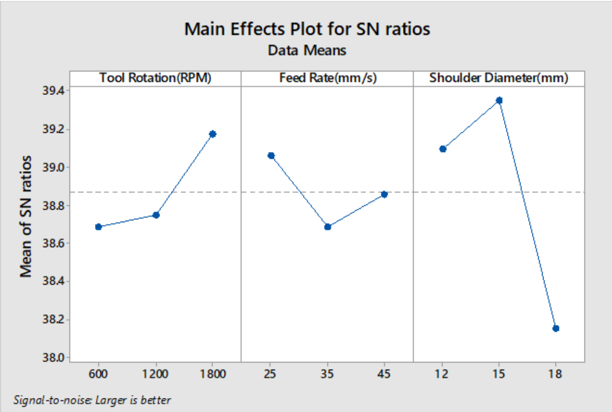

Figure 6: Effects of Process Parameters on Hardness (S/N Data)

The hardness of the weld bead slightly increases as the speed increase from 600 rpm to 1200 rpm. There is a sharp increase in the hardness as the speed increase from 1200 rpm to 1800 rpm. The overall behavior can be predicted as the hardness increase with increase of rotating speed of the tool. The trend is same for both plots. The hardness decreases as the feed rate increase from 25 mm/min to 35 mm/min. But there is a sharp increase in the hardness as the feed rate increases from 35 mm/min to 45 mm/min. The hardness increases sharply as the diameter of the shoulder is increases from 12 mm to 15 mm but there is a sharp decrease in the hardness as the diameter of the shoulder increase from 15 mm to 18 mm. The trend of change is same for both plots.

After the observation from experimentation and from Rockwell Hardness test for hardness, the data thus obtained is used in MINITAB software for the calculations of S/N ratio and mean. The table below shows the calculations of Hardness versus rotating speed of tool, feed rate and shoulder diameter at their different levels.

Table 2 Response Table for Signal to Noise Ratios

Level	Speed	Feed	Diameter
1	38.68	39.06	39.10
2	38.75	38.69	39.35
3	39.17	38.86	38.15
Delta	0.49	0.37	1.20
Rank	2	3	1

Larger is better

For Temperature

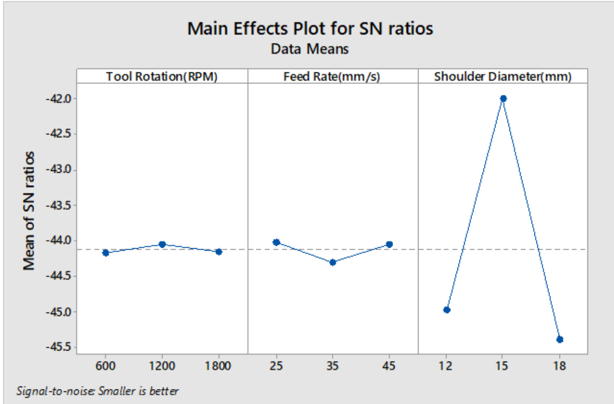

Figure 7: Effects of Process Parameters on Temperature (S/N Data)

The temperature of the weld bead is increasing linearly with increase of speed. The trend is opposite in both the plots. Temperature of the weld bead is increasing as the tool rotation speed increases from 600 rpm to 1200 rpm. There is slight decrease in the temperature of the weld bead as the tool rotation speed increases from 1200 rpm to 1800 rpm.

The temperature is decreasing as the feed rate increases from 25 mm/min to 35 mm/min. There are detectable increases in the temperature as the feed rate increase from 35 mm/min to 45 mm/min. The overall behavior can be predicted as the temperature is decreasing with increase in feed rate. The trend is opposite in both the plots.

There is a detectable increase in the temperature as the diameter of the tool shoulder increases from 12 mm to 15 mm. The temperature slightly increases with increase in diameter from 15 mm to 18 mm. The overall behavior can be predicted as the temperature is increasing with increase of shoulder diameter of the tool. The trend is opposite in both the plots.

Table 3 Response Table for Signal to Noise Ratios

Level	Speed	Feed	Diameter
1	44.17	44.02	44.98
2	44.04	44.30	41.98
3	44.15	44.04	45.40
Delta	0.13	0.28	3.41
Rank	3	2	1

Smaller is better

Conclusion

The following conclusions are drawn from the experimental study:

For Temperature Analysis

- It is concluded that temperature is influenced largely with diameter of shoulder than feed rate than speed.
- The temperature shows increasing trend with increasing speed.
- The temperature constantly with speed.
- Temperature shows decreasing trend with increase in feed rate.
- Temperature is maximum at maximum feed rate.
- Temperature shows increasing trend with increasing diameter of shoulder.
- Temperature is maximum at maximum value of shoulder diameter.

Table 4 Optimal combination for Temperature (Minimum)

Physical	Optimal Combination		
Requirements	Speed(RPM)	Feed Rate (mm/S)	Shoulder Diameter (mm)
Maximum temperature	600	35	18
	Level-1	Level-2	Level-3

For Hardness of Weld Bead (Rockwell Hardness Test)

- Hardness is highly influenced by diameter than speed than feed rate.
- Hardness shows increasing trend with increasing speed.
- Hardness is maximum at maximum value of speed.
- Hardness is minimum at feed rate 35 mm/s.
- Hardness shows somewhat decreasing trend with increasing shoulder diameter.
- Hardness is minimum at maximum shoulder diameter.

Table 5 Optimal combination for Hardness

Physical	Optimal Combination		
Requirements	Speed(RPM)	Feed Rate (mm/S)	Shoulder Diameter (mm)
Maximum Impact Strength	1800	25	15
	Level-3	Level-1	Level-2

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