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Study the Effect of Parameters of Friction Stir Welding on the Hardness of Aluminium 6063 Welded Joint and Temperature variation at different parameters

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Abstract

A Friction stir welding is a solid-state joining process in which heat is generated using a third body tool for joining of two surfaces. The objective of the present work is to investigate the effects of various parameters of friction stir welding on the heat generation and to obtain the optimal sets of process parameters so that the heat generation can be optimized. In this work the effects of various process parameters of Friction stir welding like rotation speed of tool, feed rate and the shoulder diameter have been investigated to find their effect on heat generation which is a very important factor for the joining of two metals. The temperature is measured using an infrared thermometer and heat is the direct function of temperature. Also the hardness of the welded surface plays an important role in many applications of the friction welded joint. The hardness is measured using a Vickers Hardness test. The experiments were designed by Taguchi methodology. L9 Orthogonal Array was used and Results of the experimentation were analyzed by MINITAB software analytically as well as graphically.

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

1. Introduction

It is a solid-state joining process (the metal is not melted) that uses a third body tool to join two facing surfaces. Heat is generated between the tool and material which leads to a very soft region near the FSW tool. It then mechanically intermixes the two pieces of metal at the place of the joint, then the softened metal (due to the elevated temperature) can be joined using mechanical pressure (which is applied by the tool), much like joining clay, or dough. It is primarily used on aluminum, and most often on extruded aluminum (non-heat treatable alloys), and on structures which need superior weld strength without a post weld heat treatment.

A constantly rotated non-consumable cylindrical-shouldered tool with a profiled probe is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material. The probe is slightly shorter than the weld depth required, with the tool shoulder riding a top the work surface. Frictional heat is generated between the wear-resistant welding components and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the pin is moved forward, a special profile on its leading face forces plasticized material to the rear where clamping force assists in a forged consolidation of the weld. This process of the tool traversing along the weld line in a plasticized tubular shaft of metal results in severe solid state deformation involving dynamic recrystallization of the base material.

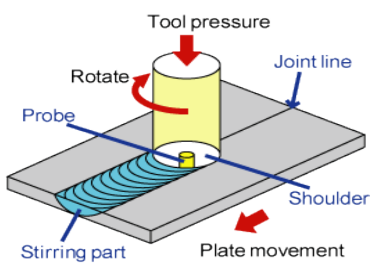

Figure: 1 FSW Welding

2 Literature Review

Friction stir welding was invented by The Welding Institute (TWI) in December 1991. TWI filed successfully for patents in Europe, the U.S., Japan, and Australia. TWI then established TWI Group-Sponsored Project 5651,Development of the New Friction Stir Technique for Welding Aluminum, in 1992 to further study this technique. The development project was conducted in three phases. Phase I proved FSW to be a realistic and practical welding technique, while at the same time addressing the welding of 6000 series aluminum alloys. Phase II successfully examined the welding of aerospace and ship aluminum alloys, 2000 and 5000 series, respectively. Process parameter tolerances, metallurgical characteristics, and mechanical properties for these materials were established. Phase III developed pertinent data for further industrialization of FSW.

Pasquale Cavaliere *et al*. (2013) have studied the effect of processing parameters on tensile, fatigue and crack behavior of several aluminum alloys. It was concluded that processing parameters in FSW affect temperature profile/heat input, defects, microstructure and residual stresses. Generally, the welding force decrease as increasing the revolutionary pitch, the welding force increases as decreasing the tool inclination angle.

Atul Suri *et al*. (2014) compare the butt welded specimen of commercial aluminum that are produced by FSW process using an improved tool at different tool rotational speeds with the similar FSW specimen produced by standard straight threaded pin tool, to ascertain the effect of rotational speed of FSW tool on surface appearance, microstructure and tensile properties. It is observed that surface appearance and the accumulation of material on the advancing side increases with the decrease of tool rotational speed at a constant feed rate i.e., 30 mm/min. At higher tool rotational speeds i.e., at1400 rpm the surface finish starts deteriorating due to excessive melting of the base metal in the weld nugget using standard tool whereas improved tool produces better surface at 1400rpm.

M. El-shennawy, adel a. Omar & m. Ayad *et al*. (2014) have performed the similar and dissimilar friction stir welding of AA7075 and concluded that Aluminum alloys 7*xxx* is age hardenable, with good combination of strength, fracture toughness, and corrosion resistance in both thick and thin wrought sections. The addition of zinc with other elements, notably copper, magnesium, and chromium, produces very high strength, including the highest strength available in any wrought aluminum alloy. Aluminum alloy 7075 is a high strength 7*xxx* alloy. Similar joint of this alloy 7075 received considerable interest from investigators from various point of views. Process parameters -including the tool profile- effect on microstructural and mechanical properties were among the major topics investigated

M. De Giorgi, A. Scialpi, F.W. Panella and L.A.C. De Filippis *et al*. (2009) have analyzed the FSW joints in order 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.

A.S. Vagh, S. N. Pandya *et al*. (2014) carry out the Friction stir welding orthogonal DOE technique is used to analyse effect of major process parameters Tool Traverse Speed and Tool Pin Profile. The joint efficiency of the AA 2014percentage elongations of all the joints are far lower than those of the base materials. The highest strength is obtained at Tool Design Highest elongation is obtained at Tool Design travel speed. From the ANOVA, it can be concluded that the Tool Design is the main input parameter that has the highest statistical influence on Tensile strength (74.01%) and nugget hardness (86.74%). It is also found that, there is very minor variation in the mechanical properties by changing the Tool travel speed.

Sivakumar, Vignesh Bose, D.Raguraman, D. Muruganandam *et al*. (2012) have demonstrated the extensive research effort that continues to progress the understanding of FSW of aluminium alloys and its influence on their microstructure and properties. It identifies a number of areas that are worthwhile for further study. From an engineering perspective, there is a need to investigate the occurrence and significance of flaws in friction stir welds. In particular, the influence of tool design on flaw occurrence and the development of nondestructive testing techniques to identify flaws in both lap and butt welds would be beneficial. Metal flow modeling may have a role to play here, though capturing this aspect of the thermomechanical behavior remains a significant challenge.

Woei-Shyan Lee and Tao-Hsing Chen *et al*. (2008) examined the dynamic deformation behavior, fracture characteristics and microstructural evolution of high-strength weldable The results have shown that the flow stress of the Al-Sc alloy increases with an increasing strain rate. The workhardening rate also increases with increasing strain rate, but decreases with increasing strain as a result of limited dislocation motion within the microstructure. The results have also revealed that the strain rate sensitivity increases but the activation volume decreases with an increasing work hardening stress.

W M Thomas *et al*. (1999) experimentally find that unlike aluminium and most non-ferrous materials, which show little or no visible change during FSW owing to increase in temperature, a colour change occurred when welding steel. The tool shoulder reached a bright orange colour within a few seconds of making contact with the plate, which indicated an approximate temperature of over 1000°C. Also, as the tool travelled along the seam, the weld track behind the trailing edge of the rotating tool appeared orange/bright red (900-1000°C). This colour changed to a darker cherry red (about 600°C) 25mm from behind the tool. The temperature was also dependent on rotational speed, increasing with increasing speed.

H.J. Liu , H. Fujii , M. Maeda, K. Nogi *et al*. (2003) experimentally concluded that a softened region, composed of a weld and two HAZs, has clearly occurred in the friction-stir-welded joints of the 2017-T351 aluminum alloy, thus the tensile properties of the joints are lower than those of the base material. The welding parameters have significant effects on the tensile properties and fracture locations of the joints. When the revolutionary pitch is greater than a definite value (e.g. 0.13 mm/rev), some void defects exist in the joints, the tensile properties of the joints are considerably low, and the joints are fractured at the weld center.

Yu E Ma, BaoQi Liu, ZhenQiang Zhao *et al*. (2013) studied experimentally the crack growth rates under three different R ratio fatigue loads. For three different welding parameters the experimental data from all specimens was compared Even though had different rotation speed, welding speed and R ratio, the crack growth rate of these samples tended to be the same tendency. It was found that the crack growth rate in weld nugget of Al-Li alloy 2198-T8 friction stir welded was mainly decided by the microstructure, not the R ratio as common understanding.

Paul A. Colegrove Hugh R. Shercliff and RudolfZettler *et al*. (2007) have been developed for predicting the heat generation and temperature field using the thermal and flow properties of the material being welded, the process conditions and the dimensions of the tool and workpiece. An analysis was done using a trial weld in 7449 aluminum alloy to determine the parameters important to heat generation. Results showed that the deformation under the shoulder was greater at a lower rotation speed. This agreed with the flow indicated by the weld macrosections. Both high rotation speeds and harder materials caused more localized deformation near the tool surface.

N. T. Kumbharand K. Bhanumurthy *et al*. (2012) performed a friction stir welding of Al 5052 with Al 6061 Alloys and concluded the following friction stir welding of dissimilar materials AA5052 and AA6061 was successfully performed. It was observed that at higher rotation speeds, the normal load and spindle torque requirement decreased.

S.K.Selvam, T.Parameshwaran Pillai *et al*. (2013) has analyzed the Heavy Alloy Tool In Friction Stir Welding and concluded that when we keep 8 welding different speeds for CFD, maintaining constant travel speed as 102mm / min and optimum speed as 350RPM, the tool life will increase. The maximum temperature in the FSW process can be achieved by increasing both welding speed and the rotating speed.

Masoud Jabbari *et al*. (2013) have studied the effect of the Preheating Temperature on Process Time in Friction Stir Welding of Al 6061-T6 .An analytical model was developed to simulate the contact temperature in the friction stir welding (FSW).This second order equation which contains thermal characteristics and welding parameters was compared and validated by experimental data in the literature. The effect of the preheating temperature on the process time was investigated. The results show that the increase of the preheating temperature not only develops the weld quality, but it also decreases the total process time.

Sachindra Shankar, Dharmendra Kumar Prasad, Shabbir Ali, *et al*. have studied surface morphologies and defects of friction stir welded AA6101 Aluminum Alloy. From the experimental analysis of lap joint of the AA6101 aluminum alloy he conclude that lap joint of the AA6101 aluminum alloy was successfully produced by friction stir welding. Plunging action should be kept at optimum value otherwise, it will lead to vertical line defects and hole defects. The rotational and welding speeds should be kept at optimum value otherwise; it will result in horizontal line defect.

Haşim Kafali *et al*. (2011) studied the joining of AA6013-T6 to itself was successfully carried out using a friction stir welding technique. The fatigue, tensile, microstructure, microhardness and EDX analysis of friction stir welded AA6013-T6 have been studied in the present work. These conclusions have been obtained the microstructure of the welding zone in the friction stir welded AA6013 T-6 was divided into four zones are base material, heat affected zone (HAZ), thermo-mechanical affected zone (TMAZ) and weld nugget. EDX measurements clearly show that both the parent material and the weld region consist of relatively homogenous distributions of the fine and coarse Mg_2Si particles.

3. Experimental Methodologies

The Taguchi method is a well-known technique that provides a systematic and efficient methodology for process optimization and this is a powerful tool for the design of high quality systems. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. This is an engineering methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce high-quality products with low development and manufacturing costs. Signal to noise ratio and orthogonal array are two major tools used in robust design.

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

1. Nominal is the best
2. Smaller the better
3. 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:

$$S/N = -10 * \log(\Sigma(1/Y^2)/n)$$

Where, S/N = Signal to Noise Ratio,

n = No. of Measurements, y = Measured Value

The influence of each control factor can be more clearly presented with response graphs. Optimal cutting conditions of control factors can be very easily determined from S/N response graphs, too. Parameters design is the key step in Taguchi method to achieve reliable results without increasing the experimental costs. If there is an experiment having 3 factors which have three values, then total number of experiment is 27. Then results of all experiment will give 100 accurate results. In comparison to above method the Taguchi orthogonal array make list of nine experiments in a particular 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.

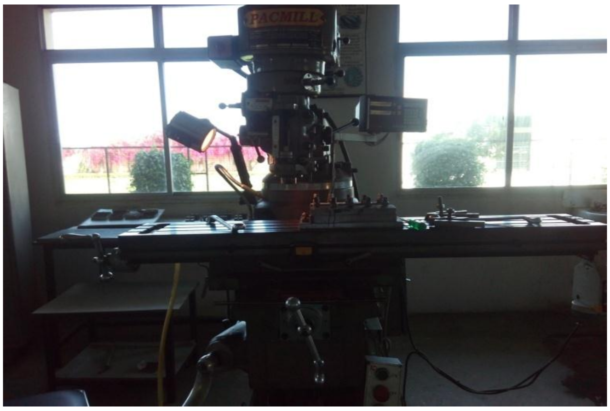

Figure 2: Vertical Milling Machine with some special Attachments and modifications

The specially designed toll made of HS 13 is used to for stirring purpose. A butt joint is made using Aluminium 6063 as working material using three parameters as rotating speed of tool, feed rate and the shoulder diameter of the tool. The various levels of rotating speed are 970, 1200, 1950 rpm. Similarly the various levels of feed rate are 30, 40, 50 mm/min also the levels of shoulder diameter are 12, 15, 18 mm

Hardness

The Metals Handbook defines hardness as Resistance of metal to plastic deformation, usually by indentation. However, the term may also refer to stiffness or temper, or to resistance to scratching, abrasion, or cutting. It is the property of a metal, which gives it the ability to resist being permanently, deformed (bent, broken, or have its shape changed), when a load is applied. The greater the hardness of the metal, the greater resistance it has to deformation.

Infrared Thermometer

An infrared thermometer is device which measure temperature from a point of the thermal radiation emitted by the object being measured. These are also called laser thermometers. These are non-contact thermometers or temperature guns, to describe the device's ability to measure temperature from a distance. By knowing the amount of infrared energy emitted by the object and its emissivity, the object's temperature can often be determined

Figure 3: Infrared Thermometer

Rockwell Hardness Test

Rockwell & Rockwell Superficial tests consists of forcing an indentor (Diamond or Ball) into the surface of a test piece in two steps i.e. first with preliminary test force and thereafter with additional test force and then measuring depth of indentation after removal of additional test force (Remaining preliminary test force active) for measurement of hardness value.
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.

In case of 'RASN' series machines for Rockwell & Rockwell superficial tests a preliminary test force in first applied and then indicator is automatically set for zero. Quickly thereafter an additional test force is applied without removing the preliminary test force. When the penetration is stabilised, the additional test force is removed and the hardness number is shown directly on the indicator.

Figure 4: Rockwell Hardness Test Appratus

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 has 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 a 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 Calcius
1	970	30	12	86.75	194
2	970	40	15	93.5	116
3	970	50	18	81	195
4	1200	30	15	95.75	130
5	1200	40	18	75.25	207
6	1200	50	12	93.25	156
7	1950	30	18	90	165
8	1950	40	12	93.5	191
9	1950	50	15	92.25	138

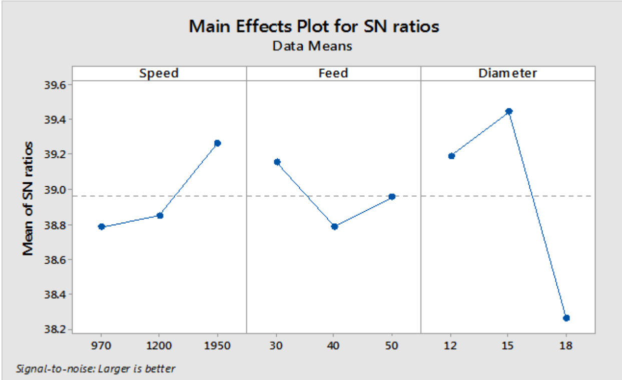

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Figure 6: Effects of Process Parameters on Hardness (S/N Data)

The hardness of the weld bead slightly increases as the speed increase from 970 rpm to 1200 rpm. There is a sharp increase in the hardness as the speed increase from 1200 rpm to 1950 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 30 mm/s to 40 mm/s. But there is a sharp increase in the hardness as the feed rate increases from 40 mm/s to 50mm/s. The trend of change is same for both the plots. 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.

Table 2 Response Table for Signal to Noise Ratios

Level	Speed	Feed	Diameter
1	38.78	39.16	39.19
2	38.85	38.79	39.45
3	39.27	38.95	38.26
Delta	0.48	0.37	1.18
Rank	2	3	1

Larger is better

For Temperature

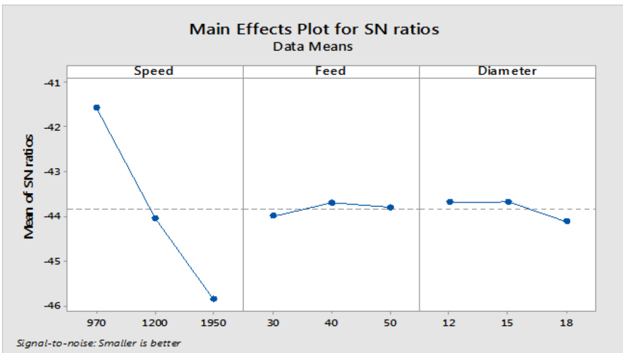

Figure 7: Effects of Process Parameters on Temperature (S/N Data)

The temperature of the weld bead is increasing linearly with increase of speed. The trend is opposite in both the plots. The temperature is decreasing as the speed increases from 30 mm/s to 40 mm/s. There are detectable increases in the temperature as the feed rate increase from 40 mm/s to 50 mm/s. The overall behavior can be predicted as the temperature id 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	-41.58	-44.00	-43.69
2	-44.05	-43.70	-43.68
3	-45.87	-43.80	-44.13
Delta	4.29	0.30	0.45
Rank	3	1	2

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 speed than diameter of shoulder than feed rate.
- The temperature shows increasing trend with increasing speed.
- The temperature increase linearly with speed.
- Temperature shows decreasing trend with increase in feed rate.
- Temperature is maximum at minimum 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 Impact Strength	970	40	12
	Level-1	Level-2	Level-1

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 40 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	1950	30	15
	Level-3	Level-1	Level-2

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