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Research Article

Study the Effect of Parameters of Friction Stir Welding 0n the Impact Strength of Aluminium 6063

Sudhir Kumar[#*] and Pardeep Kumar[#]

[#]Department of Mechanical Engineering MIET, Kurukshetra, Haryana, India

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Abstract

The friction stir welding is new method of joining processes used recently in many engineering industry. The objective of the present work is to investigate the effects of the various parameters of friction stir welding on the impact strength and to obtain the optimal sets of process parameters so that the impact strength 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 impact strength of Aluminium 6063..Morever the impact strength was calculated using a Charpy V-notch test on Impact Testing Machine. Test method of IS: 1757:1988 is used for investigation at temperature of 40c. 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.

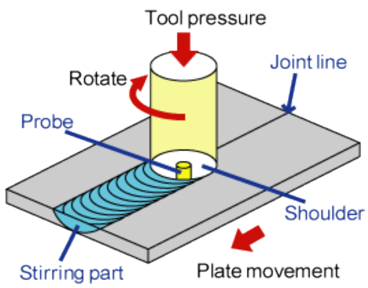

Figure: 1 FSW Welding

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

*Corresponding author **Sudhir Kumar** is a M.Tech Scholar **and Pardeep Kumar** is working as Assistant Professor

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*. 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) has 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) has 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) has 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) has 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*. (2016) has 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) investigated that 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.

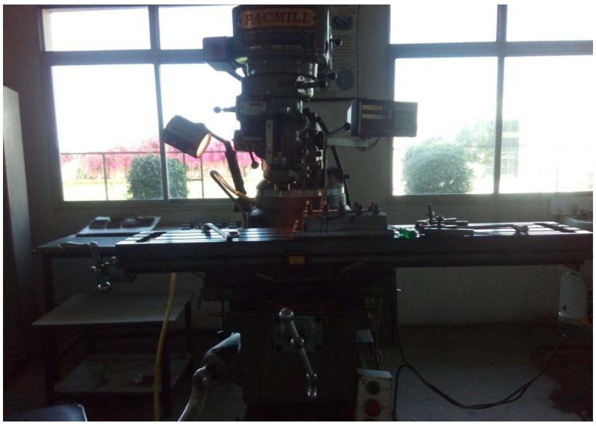

Figure 2: Vertical Milling Machine with some special Attachments and modifications

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

Impact Strength

Impact is a very important factor in determining the life of a structure or machine.e.g , in an aircraft, impact can take place by a bird during takeoff and landing the aircraft may be struck by debris that is present on the runway, and as well as other causes. Thus the impact strength must be calculated for the safety and to design a component of high factor of safety.

Impact tests are used in studying the toughness of material. Toughness is a factor of its ability to absorb energy during deformation. Brittle materials have low toughness as a result of the small amount of plastic deformation that they can endure. The impact value of a material can also change with temperature. Generally, at lower temperatures, the impact energy of a material is decreased. The size of the specimen may also affect the value of the Izod impact test because it may allow a different number of imperfections in the material, which can act as stress risers and lower the impact energy.

Charpy Impact Test

Charpy impact testing involves striking a standard notched specimen with a controlled weight pendulum swung from a set height. The standard Charpy-V notch specimen is 55mm long, 10mm square and has a 2mm deep notch with a tip radius of 0.25mm machined on one face. The specimen is supported at its two ends on an anvil and struck on the opposite face to the notch by the pendulum. The amount of energy absorbed in fracturing the test-piece is measured and this gives an indication of the notch toughness of the test material. The pendulum swings through during the test, the height of the swing being a measure of the amount of energy absorbed in fracturing the specimen. Conventionally, three specimens are tested at any one temperature and the results averaged. Charpy tests show whether a metal can be classified as being either brittle or ductile. This is particularly useful for ferritic steels that show a ductile to brittle transition with decreasing temperature. A brittle metal will absorb a small amount of energy when impact tested, a tough ductile metal absorbs a large amount of energy. The appearance of a fracture surface also gives information about the type of fracture that has occurred; a brittle fracture is bright and crystalline, a ductile fracture is dull and fibrous. When a ductile metal is broken, the test-piece deforms before breaking, and material is squeezed out on the sides of the compression face. The amount by which the specimen deforms in this way is measured and expressed as millimetres of lateral expansion.

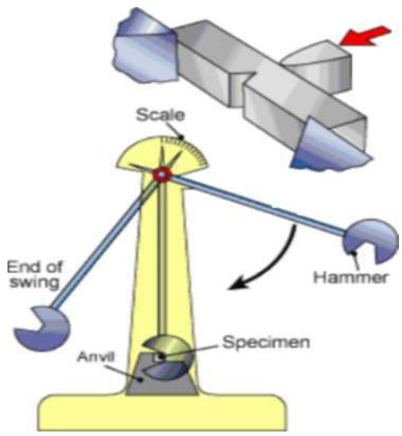

Figure 3: Charpy Test Appratus

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 4: Workpiece

Experimental Procedure

The experiments were carried out on a Vertical Milling Machine (Packmill) having some special attachments and modifications of Geeta Institute if Engineering & Technology, Kanipla Kurukshetra India. The tool of vertical milling machine is replaced with the special designed tool for friction welding. Various experiments were made at different levels of parameters.

4. Result and Analysis

Table 1 Observation table Izod Charpy Test for Impact Strength

Expt. No.	Tool Rotation(RPM)	Feed Rate(mm/min)	Shoulder Diameter(mm)	Impact Strength
1	970	30	12	10.5
2	970	40	15	9
3	970	50	18	11.5
4	1200	30	15	10.5
5	1200	40	18	12
6	1200	50	12	11
7	1950	30	18	12.5
8	1950	40	12	15
9	1950	50	15	8.5

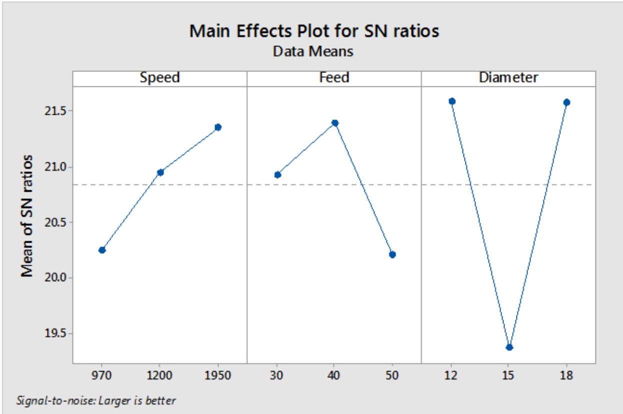

Figure 5: Effects of Process Parameters on Impact Strength (S/N Data)

Result and Discussion for Impact Strength (Izod Charpy Test)

The value of impact strength increases with increase in the rotating speed of the tool. The rate of increase of impact strength is high as the speed increases from 970 rpm to 1200 rpm. But the rate of increase of impact strength slightly decreases as the speed increases from 1200 rpm to 1950 rpm. The impact strength follows approximate linear relationship with the speed of the rotating tool. The trend is observed same in both SN Ratio and Mean Plot.

The impact strength increases sharply as the feed rate increases from 30 mm/s to 40mm/s and it decreases sharply as the feed rate increases from 40 mm/s to 50 mm/s. The trend is observed same in both SN Ratio and Mean Plot.

The impact strength is sharply decreases with increase of shoulder diameter from 12 mm to 15 mm and it sharply increases as the shoulder diameter increase from 15 mm to 18mm. . The trend is observed same in both SN Ratio and Mean Plot.

After the observation from experimentation and from izod charpy test for impact strength, the data thus obtained is used in MINITAB software for the calculations of S/N ratio and mean.

Table 2 Taguchi Analysis: Impact Strength versus S (rpm), F(mm/min), D(mm)

Speed	Feed	Diameter	Impact Strength	SNRA1	MEAN1
970	30	12	10.5	20.4238	10.5
970	40	15	9.0	19.0849	9.0
970	50	18	11.5	21.2140	11.5
1200	30	15	10.5	20.4238	10.5
1200	40	18	12.0	21.5836	12.0
1200	50	12	11.0	20.8279	11.0
1950	30	18	12.5	21.9382	12.5
1950	40	12	15.0	23.5218	15.0
1950	50	15	8.5	18.5884	8.5

Table 3 Response Table for Signal to Noise Ratios (Larger is better)

Level	Speed	Feed	Diameter
1	20.24	20.93	21.59
2	20.95	21.40	19.37
3	21.35	20.21	21.58
Delta	1.11	1.19	2.23
Rank	3	2	1

Conclusion

The following conclusions are drawn from the experimental study: (Izod Charpy Test)

- It is concluded that the impact strength highly influenced by diameter than feed than speed.
- Impact strength is increasing with increasing speed.
- Impact strength is maximum at maximum speed.
- Impact strength is maximum at feed rate 40 mm/s.
- Impact strength is minimum at maximum feed rate.
- Impact strength is minimum at diameter of shoulder 15 mm.

Table 4 Optimal combination for Impact Strength

Physical	**Optimal Combination**		
Requirements	Speed (RPM)	Feed Rate (mm/S)	Shoulder Diameter (mm)
Maximum Impact Strength	1950	40	12
	Level-3	Level-2	Level-1

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