EXPERIMENTAL STUDY OF FRICTION STIR WELDING OF AA 6061 & AA 5083 USING TAGUCHI TECHNIQUE

Er. Lokesh Mangla*, Er. Rajiv, Er. Ravinder Chaudhary*****

**** Post Graduate student in Industrial and Production Engg. at GIMT, Kurukshetra.***

***** Assistant Professor in Mechanical at GIMT, Kurukshetra.***

****** Assistant Professor in Mechanical at SKIET, Kurukshetra.***

Abstract: Friction stir welding, a solid state joining technique, is widely being used for joining Al alloys for aerospace, marine automotive and many other applications of commercial Importance. FSW trials have to carry out using a vertical milling machine on Al 6061 AA5083 alloy. The tool geometry was carefully chosen and fabricated to have a nearly flat welded interface**.** The objective of this research is to quantify the relationship between spindle speed, travel speed, and tool tilt angle parameters for friction stir welding (FSW) at high spindle speeds (1200rpm-4600rpm) to optimize the rockwell hardness testing of Al6061 and AA5083 alloy. Taguchi design is used for the current research work. This technique provides straight evaluation of the influence of the investigated parameters on the friction stir welding outcomes i.e. Rockwell Hardness.

Keywords: Friction Stir Welding (FSW), work piece: Al-6061, AA5083 alloy, input parameters: Spindle Speed, Travel Speed, Tool Tilt Angle, Response Parameter: Rockwell Hardness.

I. INTRODUCTION

Friction-stir welding (FSW) 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. The solid-state nature of FSW leads to several advantages over fusion welding methods as problems associated with cooling from the liquid phase are avoided. Issues such as porosity, solute redistribution, solidification cracking and liquation cracking do not arise during FSW. In general, FSW has been found to produce a low concentration of defects and is very tolerant of variations in parameters and materials.

In the present study, only friction stir welding process is taken in to the consideration. All the experimental work is performed on Friction-stir welding process. The process parameters and the levels are selected after the study of previous work performed.

II. LITERATURE REVIEW

Shige Matsu et. al. (2003) dealt with Joining of 5083 and 6061 aluminum alloys by friction stir welding. States that in this process, a rotating tool travels down the length of contacting metal plates, and produces a highly plastically deformed zone through the associated stirring action. The localized heating zone is produced by friction between the tool shoulder and the plate top surface, as well as plastic deformation of the material in contact with the tool.

K. Kimapong and Watanabe et. al 2004 investigated the effects of pin rotation speed, position of the pin axis, and pin diameter on the tensile strength and microstructure of the joint. The main results obtained are as follows: butt-joint welding of an aluminum alloy plate to a steel plate was easily and successfully achieved. But When pin rotation speed was too slow, i.e., 100 rpm, the pin wore out in a short time due to insufficient heat generation and insufficient plasticization of the Al.

N. T. Kumbhar et. al. 2008 dealt with Friction Stir Welding of Al 6061 Alloy. States that during the friction stir welding, extensive deformation is experienced at the nugget zone and the evolved microstructure strongly affects the mechanical properties of the joint. FSW trials were carried out using a vertical milling machine on Al 6061 alloy.

D.M. Rodrigues et. al. 2009 dealt with Influence of friction stir welding parameters on the micro structural and mechanical properties of AA 6016-T4 thin welds. States that in present work friction stir welds produced in 1 mm thick plates of AA 6016-T4 aluminum alloy, with two different tools, were analyzed and compared concerning the microstructure and mechanical properties. For each tool, the welding parameters were optimized in order to achieve non-defective welds, assuming a relation between the welding parameters and the energy input per unit of length of the weld, a conical shoulder with inclination cavity and 10 mm in diameter and a scrolled shoulder with 14 mm in diameter. The geometry of the probe was the same for both tools, a cylindrical threaded probe with 3 mm in diameter, 1 mm long for the conical shoulder and 0.85 mm long for the scrolled shoulder. The conical shoulder geometry is very traditional and has already been used in numerous applications. Friction stir welds were performed parallel to the rolling direction of the plates using a conventional milling machine.

Mohamadreza Nourani et. al. 2010 dealt with Taguchi Optimization of Process Parameters in Friction Stir Welding of 6061 Aluminum Alloy: A Review and Case Study. States that study is intended to present a straightforward and computationally efficient methodology for optimizing the process parameters of friction stir welding (FSW) of 6061 aluminum alloy. In addition, a new ANOVA analysis on the L9 orthogonal array with three factors is performed and results indicate that among the parameters considered (*i.e.*, the tool rotational speed, transverse speed, and the axial force), the most significant parameter on the weld quality is the rotational speed, followed by the axial force and transverse speed. After a review of prediction and optimization models of FSW, the Taguchi optimization of a FSW process was conducted on a temperature field for the 6061 aluminum alloy.

Indira Rani M. et. al. 2011 dealt with a study of process parameters of friction stir welded AA 6061 aluminum alloy in O and T6 conditions. States the principal advantages of friction stir welding are low distortion, absence of melt related defects and high joint strength. Tool design and material plays a vital role in addition to the important parameters like tool rotational speed, welding speed and axial force. Aluminum alloys are important for the fabrication of components and structures which require high strength, low weight or electric current carrying capabilities to meet their service requirements. Among all aluminum alloys, AA 6061 alloy plays major role in the aerospace industry in which magnesium and silicon are the principal alloying elements. As the FSW process does not release toxic acids or fumes, it is an environment protective process. No consumable filler material or edge preparation is normally necessary. The distortion is significantly less than that caused by arc fusion welding techniques. By welding Aluminum alloys by fusion welding process there is possibility of cracks, porosity, alloy segregation and hot cracking and the fusion welding process completely alters microstructure and varies the mechanical properties. By FSW both similar and dissimilar materials can be successfully joined. The parameters like welding speed, tool rotational speed, axial force, tool profile has affect on the weld. From the results obtained it can be inferred that tool rotational speed and welding speed has got influence on the welded joint.

Damjan klobcar et. al. 2012 dealt with friction-stir welding of aluminum alloy 5083. States that when welding with the high frictional heat input, a) a risk of over plunging and excessive flash generation is present, b) the stirred material heats well above the re-crystallization temperature and the grain growth occurs, c) the hardness of the weld, the HAZ and the closer base alloy drops below the initial base-alloy hardness and d) an approximately 15 % lower tensile strength compared to the base alloy is obtained. In this study the weld ability when welding with a medium heat input in the optimal range of welding parameters (3 r/mm): a) the weld hardness increases slightly compared to the base alloy, b) the grains refine to half the size of the base alloy, due to the deformational hardening combined with the re-crystallization, c) the weld has a higher tensile strength, and d) for higher tool rotations of the 5083 aluminum alloy using friction-stir welding (FSW) was investigated. When welding with a low heat input (RPF = 1 r/mm): a) the weld apices become rough and a tearing takes place, due to a too low frictional heat input, b) a "tunneling" or "elongated cavity" defect is usually present, c) the weld hardness increases since the deformation hardening becomes the dominating process, and d) an approximately 15 % lower tensile strength compared to base alloy is obtained. Welding parameters, i.e., the tool-rotation speed, the welding speed and the tilt angle have an influence on the formation of welding defects, the weld apices appearance, the microstructure and the weld strength.

Morteza Ghaffarpour, et. al. 2013 dealt with Evaluation of Dissimilar Welds of 5083-H12 and 6061-T6 Produced by Friction Stir Welding. States that as the conventional fusion welding is not desirable for welding aluminum alloys, there are many works conducted on welding the aluminum alloys by FSW. These works are in regard to the effects of FSW parameters on weld quality, sheet formability after FSW, and optimization of the FSW process.

S. Jannet et. al. 2013 dealt with Comparative investigation of friction stir welding and fusion welding of 6061-T6 and 5083-O aluminum alloy based on mechanical properties and microstructure. states .In this paper, the mechanical properties of welded joints of 6061 T6 and 5083 O aluminum alloy obtained using friction stir welding (FSW) with four rotation speed (450, 560, 710 and 900 rpm) and conventional fusion welding are studied. FSW welds were carried out on a milling machine. The two plates of AA6061 aluminum alloy were Friction stir welded in the butt configuration by using conventional vertical milling machine. The two plates were placed side by side and clamped firmly to prevent the abutting joint faces from being forced apart. In this study, there are four major controllable factors each one at four levels namely rotation speed (600, 700, 800, 900 rpm), Welding speed (10, 14, 16, 19 mm/min), pin tool length (5.3, 5.5, 5.7, 5.9 mm), tool pin offset distance (0.1, 0.2, 0.3, 0.4 mm). The optimum operating conditions of FSW have been obtained for two plates of aluminum alloy AA6061 welded in butt joint. The maximum temperature is obtained at 435□ C through optimized parameters using ANSYS. The obtained temperature is about 70 to 90% of the melting point temperature of the parent material. This indicated that the quality of weld is good. The ANOVA summary results of the gray relational grade indicates that pin tool length, transverse speed, rotation speed and tool pin offset distance are the relatively significant FSW process parameters, respectively, for affecting the multiple performance characteristics.

III. EXPERIMENTAL DETAIL

Due to of the non availability of specialist machine in India for FSW process, a conventional vertical milling machine was used to attempt the welding process as shown in the Figure 1 and Figure 1.1. The machine must has the ability to apply significant pressure on z axis direction, wide range of spindle speed, enough space for its working table to holding the welding assembly and rigidly during the welding operation.

Fig 1: Pictorial view of speed variation **Fig 1.1: Friction Stir Welding**

Tool design

The design of the tool is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed. It is desirable that the tool material is sufficiently strong, tough, and hard wearing at the welding temperature. Hot-worked tool steel such as H13 has proven perfectly acceptable for welding aluminum alloys within thickness ranges of 0.5 – 50 mm.

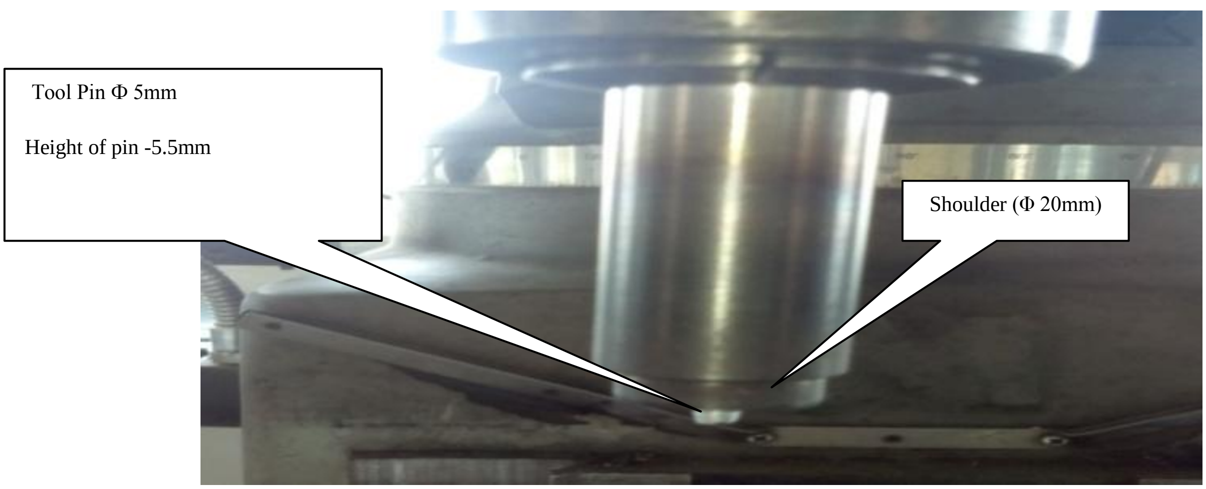


Fig 1.2: H13 Tool design

Experimental Set Up

The purpose of this study is analyzing the effect of FSW process parameters on response variable such as Rockwell Hardness test. Also, it is intended to ascertain the ranges of different parameters required for the experimental design methodology used in this work. Observations are made by using design of experiment shown in table 2.1.

Sr. no.	Tool rotation speed (in r.p.m.)	Table Feed rate in (mm)	Tool tilt angle (in degree)	Rockwell hardness test
1.	1200	15	0.5	24
2.	1200	20	1.0	22
3.	1200	25	1.5	27
4.	1200	30	2.0	32
5.	1950	15	1.0	25
6.	1950	20	0.5	23
7.	1950	25	2.0	28
8.	1950	30	1.5	33
9.	3080	15	1.5	30
10.	3080	20	2.0	44
11.	3080	25	0.5	43
12.	3080	30	1.0	50
13.	4620	15	2.0	49
14.	4620	20	1.5	59
15.	4620	25	1.0	60
16.	4620	30	0.5	55

Table 2.1: Design of Experiment and rock well hardness after testing

IV. RESULTS AND DISCUSSION

The Al 6061 AA5083 alloy is used for the experimentation. This is mounted on Friction Stir Welding.

Level	**Speed**	**Feed**	**Tilt Angle**
1	28.30	29.73	30.58
2	28.63	30.59	31.09
3	32.27	31.45	30.99
4	34.90	32.31	31.43
Delta	6.60	2.59	0.85
Rank	1	2	3

Table: 3.1 signal to noise ratio

Source	DF	Adj SS	Adj MS	F-Value	P -Value
Speed	3	2230.00	776.667	32.36	0.000
Feed	3	237.00	79.000	3.29	0.100
Tilt Angle	3	20.00	6.667	0.28	0.840
Error	6	144.00	24.000	_	_
Total	15	2731.00	_	_	_

Table: 3.2 response table for means

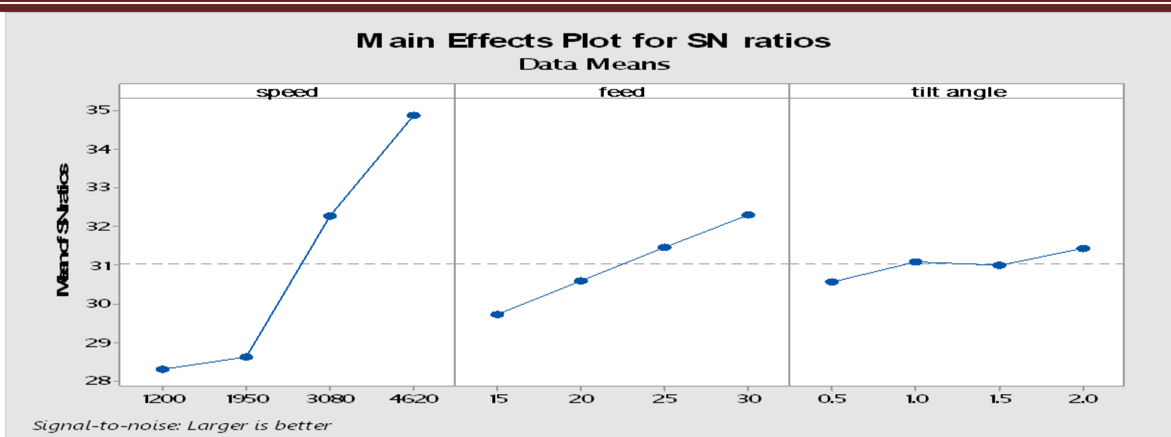
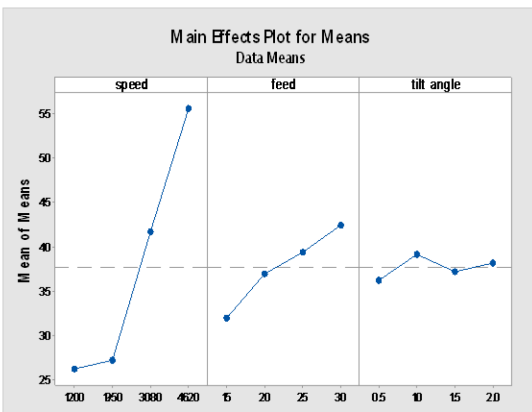


FIG :3.1 main effects for signal to noise ratio



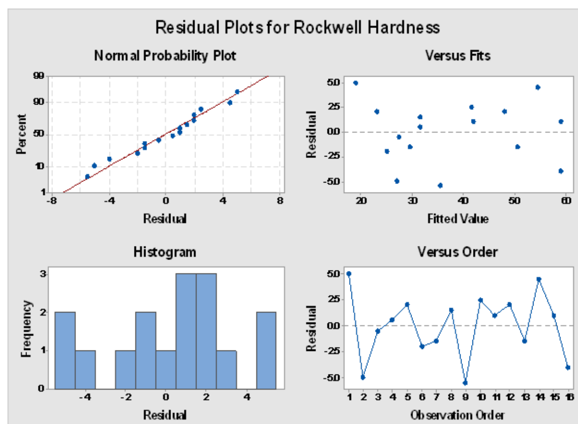


FIG: 3.3 main effects for means

Fig:3.2 Residual plots for Rockwell hardness

Regression Equation

Rockwell Hardness = 37.75*11.50 speed_1200-10.50 speed_1950

+ 4.00 speed_3080+ 18.00 speed_4620 - 5.75 feed_15 -0.75 feed_20 + 1.75 feed_25

+ 4.75 feed_30 - 1.50 tilt angle_0.5 + 1.50 tilt angle_1.00.50 tilt angle_1.5 + 0.50 tilt angle_2.0

The various taguchi analysis are shown in the tables and figure above in the result and discussion. The Rockwell hardness is evaluated first with analysis of variance in Minitab software table 3.1, 3.2 shows the signal to noise ratio for means the probabilistic value below 0.05 shows the goodness of the model. furthe in the figure shown above i.e 3.1 shows that Rockwell hardness increase with increase of speed, feed and tilt angle which is in the close agreement with some of researcher. Residual plots of the hardness are shown in figure 3.2. Figure 5.3 shows the interaction and quadratic effects of factors along with their main effects can be known by normal probability plot of the effects of factors as shown in above. The factors which are not significant are very close to the normal probability line. This is due the fact that the effects of all such factors are normally distributed with zero mean and thereby are negligible. The adequacy of the model is checked using the normal probability plot of residuals. It can be observed that the points are very close to the normal probability line and thus evidencing the model adequacy. It can be observed that the points representing the residuals are randomly scattered. Thus, the model formulated for prediction of tensile strength as represented by figure is adequate. Figure 3.1: Shows effect of various FSW parameters on the mean of S/N ratio of Rockwell hardness plotted utilizing the machining results obtained. From the figure, it is observed that the mean value of S/N ratio of the Rockwell hardness is increase by increasing the feed from 1200 to 4620 mm/min. The mean of S/N ratio of Rockwell hardness rises constantly by increasing the value of 15 to 30 mm/min. The mean of S/N ratio of MRR is also increased by increase the Tilt Angle 0.5 to 2.0 Radian kgf/cm^2.

V. CONCLUSION

From the above study is concluded that:

a) The Friction stir welding is used to find the quality of Rockwell hardness which seems is better than the digital radiography and any other techniques.

b) The welding parameter like Feed, Speed, tilt angle and transverse speed of tool plays a very important role in defining the weld quality.

c) As Transverse Speed Of Tool Increase, The Amount Heat Input For The Process Decreases And Hence Defect Which Is Also Find In Closed Relation With Some Of The Researcher.

d) It is also concluded that as the speed is increased the hardness is also improved.

REFERENCES

- I . Shigematsu, y.-j. Kwon, k. Suzuki, t. Imai, n. Saito (2003), joining of 5083 and 6061 aluminum alloys by friction stir welding, institute for structural and engineering materials (isem), national institute of advanced industrial science and technology (aist), 2266-98, anagahora, shimoshidami, moriyama-ku, nagoya, aichi 463-8560, japan.
- K. Kimapong and t. Watanabe,(2004) friction stir welding of aluminium alloy to steel.
- N. T. Kumbhar and k. Bhanumurthy*friction stir welding of al 6061 alloy ,asian j. Exp. Sci., vol. 22, no. 2, 2008; 63-74.
- D.M. Rodrigues, A. Loureiro, C. Leitao, R.M. Leal, B.M. Chaparro , (2008) journal homepage: www.elsevier.com/locate/matdes P. Vilaça, Influence of friction stir welding parameters on the microstructure and mechanical properties of AA 6016-T4 thin welds.
- Mohamadreza Nourani, Abbas S. Milani, Spiro Yannacopoulos,(2011) Taguchi Optimization of Process Parameters in Friction Stir Welding of 6061 Aluminum Alloy: A Review and Case Study ,Published Online February 2011.
- N. Bhanodaya kiran babu1, a. Prabhu kumar and m. Joseph davidson,(2011) a review of friction stir welding of aa6061 aluminium alloy, issn 1819-6608arpn journal of engineering and applied sciences, vol. 6, no. 4.
- Indira rani m., marpu r. n. and a. c. s. kumar, a study of process parameters of friction stir welded aa 6061 aluminum alloy in o and t6 conditions, arpn journal of engineering and applied sciences, vol. 6, no. 2, february 2011, issn 1819-6608.
- Qasim m doos1* and bashar abdul wahab(2012)experimental study of friction stir welding of 6061-t6 aluminum pipe issn 2278 – 0149, vol. 1, no. 3, october 20122012 ijmerr.
- Morteza ghaffarpour, sina kolahgar, bijan mollaei dariani, and kamran dehghani, evaluation of dissimilar welds of 5083-h12 and 6061-t6 produced by friction stir welding, DOI: 10.1007/s11661-013-1739-2 ,The Minerals, Metals & Materials Society and ASM International 2013.

- S. Jannet, P.K. Mathews, R. Raja,(2013) Comparative investigation of friction stir welding and fusion welding of 6061-T6 and 5083-O aluminium alloy based on mechanical properties and microstructure, Received 09.10.2013; published in revised form 01.12.2013.

AUTHORS BIOGRAPHIES

LOKESH MANGLA passed his diploma in Mechanical engineering In 2008 from haryana state board of technical education and B.tech In 2008 From kurukshetra universitsy kurukshetra and pursuing M.tech from kuk.

RAJIV KUMAR passed his B.tech from JIET, jind in 2005 and M.tech from GJU hisar in 2010. Presently he is working as the assistant professor in GIMT kurukshetra.

RAVINDER CHAUDHARY passed his B.Tech In 2009 and M.Tech from SUSCET TANGORI. He is working as a H.O.D in the Department of Mechanical Engineering at SKIET Kurukshetra. He has more than four years of teaching experience. He has 10 publications in International journal and 3 publication in national conference proceeding.