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Effect of Process Parameters of Friction Stir Welded Joint for Similar Aluminium Alloys H30

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Abstract
In this paper the effect of process parameters of friction stir welded joint for similar aluminium alloys H30 was studied. Taper cylindrical with three flutes all made of High speed steel was used for the friction stir welding (FSW) aluminium alloy H30 and the tensile test of the welded joint were tested by universal testing method. The optimization done using detailed mathematical model is simulated by Minitab17. In this investigation, an effective approach based on Taguchi method, has been developed to determine the optimum conditions leading to higher tensile strength. Experiments were conducted on varying rotational speed, transverse speed, and axial force using L9 orthogonal array of Taguchi method. The present study aims at optimizing process parameters to achieve high tensile strength.
Key words: Friction stir welding (FSW) Tool, CNC milling machine, Aluminium alloy H30, Minitab17, Tensile test, taper cylindrical tool.

I. INTRODUCTION

Friction stir welding is a version of pressure welding processes. It was recently developed in England by welding institute (TWI) in 1991.It can be created high quality weld by using CNC milling machine because using same movement conditions but tool is different. Friction stir welding is extensively used for Al, Mg .Cu, Ti, for work pieces that could not welded by conventional types of welding and different applications because of economical and quality consideration [1]. This technique has been extended to similar as well as dissimilar welding of the above mentioned alloys and also to the welding of steels [2]. FSW done on CNC milling machine for small work pieces to professional single purpose robotic machine in orbital FSW in steel pipes welding in oil industries [3]. The schematic of friction stir process shown in Figure 1.

Friction Stir Welding has advantages over the conventional welding techniques some of which include very low distortion, no fumes, porosity or spatter, no consumables (no filler wire), no special surface treatment and no shielding gas requirements. so it has been widely used in the aerospace, shipbuilding, automobile industries and in many applications.

In FSW, there have been lots of efforts to understand the effect of process parameter on flow behavior, microstructure formation and hence mechanical properties of FSW joints. To study the effect of FWS process parameters, most workers follow the traditional experimental techniques, i.e. varying one parameter at a time and keeping others constant. In last experiment we were taken three parameters like rotational speed, travel speed and constant welding depth. Now in recent paper we were changed the constant parameter that means we taken axial force instead of welding depth.

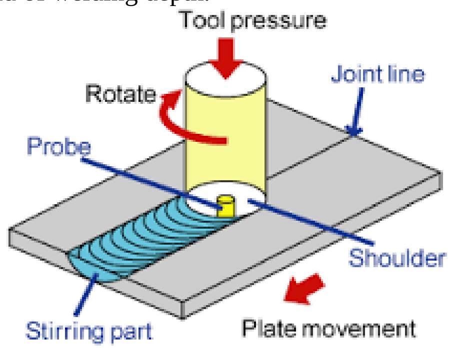

Fig. 1: Schematic of Friction Stir Welding.

Taguchi method is a power full method which can improve the performance of the product is that the optimization of process parameters of similar alloy H30-H30 using Taguchi method has not repeated yet. Taguchi method is used to analyze the effect of process parameter (i.e. rotational speed, transverse speed, and axial force) for optimizing tensile strength of FS Welds of similar aluminium alloys H30-H30.

II. LITERATURE REVIEW:

In Omid Ali Zargar project he was using three type of tools, straight cylindrical, taper cylindrical and triangular tool all made of High speed steel (Wc-Co) for the friction stir welding (FSW) aluminum alloy H20 –H20 and test the mechanical properties of the welded joint by tensile test and vicker hardness test[1].

M. Pouranvari studied the effect of transient liquid phase (TLP) bonding condition on the mechanical properties of GTD-111 nickel base superalloy investigated. [2].

N. T. Kumbhar and K. Bhanumurthy was carefully chosen the tool geometry and fabricated to have a nearly flat welded interface. Important process parameters that control the quality of the weld are axial force, rotation speed (rpm), traverse speed (mm/min) and tool tilt angle and these process parameters were optimized to obtain defect free welded joints. It is observed 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 [3]. In this present study FSW of AZ31B are used to improve the process parameters [4].

III. TAGUCHI METHOD

Optimization of process parameter is the important in the Taguchi method to achieving high quality without increasing cost. It can improve quality and the optimal process parameters obtained from the Taguchi method and other noise factors. Taguchi method is experimental design easy to apply for many engineering applications. Taguchi method can be used to quickly narrow the scope of a research project or to identify problems in a manufacturing process.

When the number of the process parameters increases, a large number of experiments have to be carried out. To solve, the Taguchi method uses a special design of orthogonal array to study the entire process parameter with only a small number of experiments.

3.1 FSW Process Parameters:

Process parameters plays important role in deciding the weld quality. The process parameter was selected shown in table.

Table1. Process Parameters with corresponding levels

Sr. No	Process Parameters	Range	Level 1	Level 2	Level 3
1	Rotational speed	1200-1600 rpm	1200	1400	1600
2	Travel speed	10-30 mm/min	10	20	30
3	Axial Force	2000-6000N	2000	4000	6000

IV. MATERIALS AND METHODOLOGY

4.1 **Aluminium alloy H30:**

The work piece materials selected for this investigation were AA6082-T6 and 6082-T6 aluminium alloys sheets of 6.5 mm thickness having chemical composition and shown in the Table 1. In the present study, size of sheets is 100mm x 70mm of AA6082-T6 and AA6082-T6 were cut for welding by FSW.

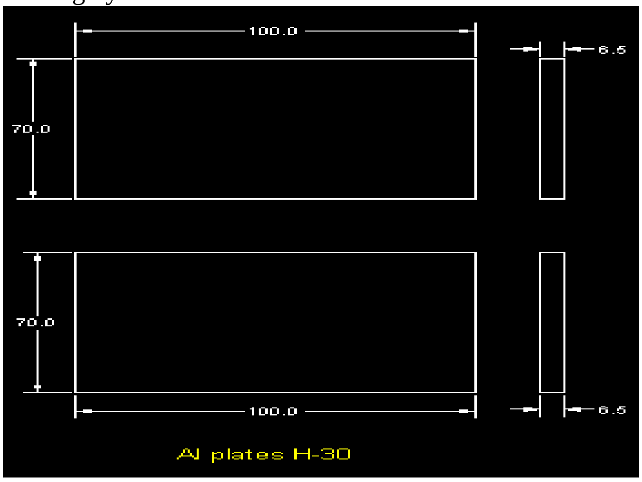

Fig.2 Work piece Dimensions

Table 2 .Chemical Composition of H30:

Element	Mg	Si	Fe	Cu	Cr	Zn	Ti	Mn	Al
%	0.69	0.60	0.30	0.10	Nil	0.06	Nil	0.38	Balance

1. Alloy Designations:

Aluminium alloy 6082 also corresponds to the following standard designations and specifications but may not be a direct equivalent:
AA6082
HE30
DIN 3.2315
EN AW-6082
ISO: Al Si1MgMn
A96082

4.2 Selection of Tool:

The friction stir welding tool consists of a pin, or probe, and a shoulder. Contact between pin and workpiece creates frictional and heating and softens the workpiece material contacting the shoulder to the workpiece increases the workpiece heating, expands the zone of softened material.

1. Material:

Friction stir welding is a thermo mechanical deformation process where material of base plate deforms due to the temperature created by shoulder. Friction stir weld requires the proper tool material selection for the desired application.

2. HSS:

Taper Cylindrical tool with three flutes used in present study which was made of high-speed tool steel. This is most commonly used material and has some good mechanical properties like easy availability and machinability, thermal fatigue resistance, wear resistance, especially for aluminium and copper.

4.3. Design of tool:

Tool was made in two different parts due to the length of pin, one is shoulder for holding purpose and another is tip or pin which is penetrated in base material.

A. Taper cylindrical tool with three flutes**:** the length of pin is 5mm and its shape is paper cylindrical. Also three flutes are provided on pin for wear and also provided the circular shape on the shoulder as shown below. All the dimensions of tool is also shown in fig.3

Fig. 3 Friction stir welding taper cylindrical tool with three flutes

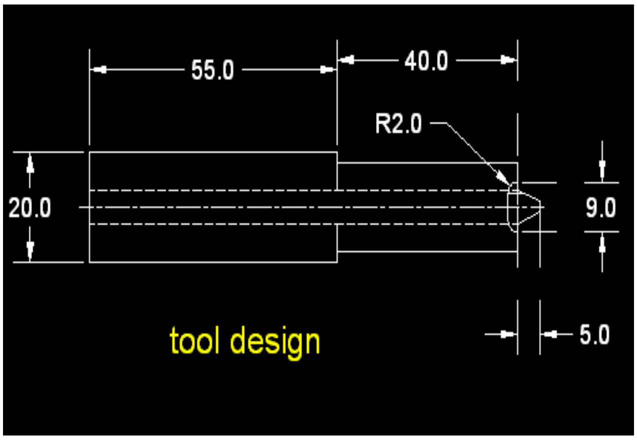

Fig.4 Taper cylindrical tool with dimensions**:**

4.4 Friction Stir Welding Procedure:

Nine experiments parameters have been performed on Al-6082 plates by L9 orthogonal array. The three factors used in this experiment are the rotating speed, axial force and travel speed. The factors and the levels of the process parameters are presented in Table.3 and these parameters are taken based on the previous trials to weld the FSW of aluminium's. The experiments are performed on a vertical milling machine.

Table.3 Experimental layout of L9 Orthogonal array

Experiment	Rotational speed	Travel speed	Axial Force
1	1200	10	1200
2	1200	20	1400
3	1200	30	1600
4	1400	10	1400
5	1400	20	1600
6	1400	30	1200
7	1600	10	1600
8	1600	20	1200
9	1600	30	1400

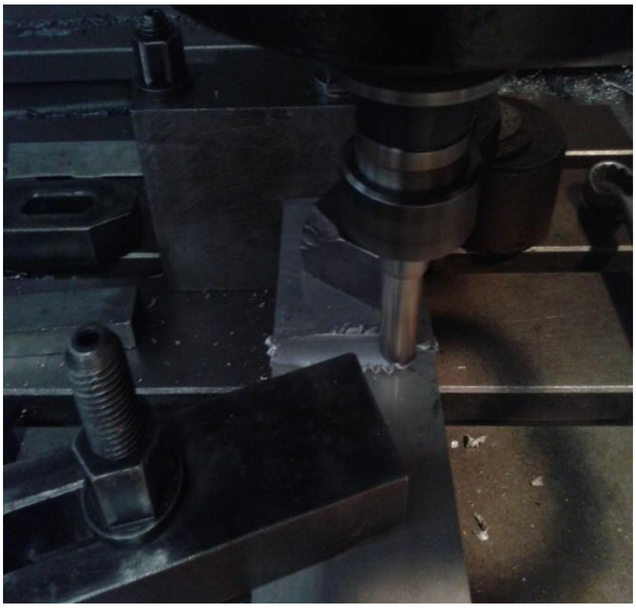

Fig.5 shows Tool on VMC

V. WELD TESTING PROCEDURE:

Tensile test performed on universal testing machine after friction stir welding. Testing performed in temperature between 10 to 30°C if A is the cross sectional area and F is the maximum force and tensile strength calculated by:

Tensile strength=F/A

Fig.6 Process Setup for Tensile Test

Fig.7 Tensile specimen before failure

Fig.8 Tensile specimen after failure

Table.4 The input parameter of orthogonal array and the output characteristics

Sr. No.	**Rotational Speed (RS) RPM**	**Travel Speed (TS) mm/Min**	**Axial Force (AF) N**	**Tensile strength (Mpa)**
1	1200	10	2000	69
2	1200	20	4000	55
3	1200	30	6000	66
4	1400	10	4000	32
5	1400	20	6000	80
6	1400	30	2000	32
7	1600	10	6000	77
8	1600	20	2000	69
9	1600	30	4000	59

VI. RESULT DISCUSSION:

6.1 Friction Stir Welded Joint Results:

We weld the mention dimension of aluminium alloy H30-H30 with the mentioned process parameter was successfully done on CNC milling machine with taper cylindrical tool (with three flutes) & then perform tensile strength test to the welded joints compare the results and make conclusion.

Fig.9 Al alloy H-30 before and after welding

6.2. S/N Ratio Analysis:

The term 'Signal' represents the desirable value (mean) for the output characteristics and the term 'noise' represents the undesirable value for the output characteristic. The S/N ratio are uses to measure the quality characteristic deviating from the desired value in Taguchi method. The S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), larger is better (LB). Larger is better S/N ratio was used here.

Larger the better characteristic

$$S/N = -10 \log10 (MSD)$$

$$MSD = (1/Y1^2 + 1/Y2^2 + 1/Y3^2 + \ldots\ldots\ldots\ldots\ldots)/n$$

Where Y1, Y2, Y3 are the responses and n is the number of trial and m is the target value of result. The highest S/N ratio was the optimum level for responses measured.

Fig.10 Tool after welding   Fig.11 work piece after welding

Table 5: S/N ratio of tensile strength of FS Welds

Sr. No.	Rotational Speed (RS) RPM	Travel Speed (TS) mm/Min	Axial Force (WF) N	Tensile Strength (UTS) Mpa	S/N Ratio
1	1200	10	2000	69	36.7770
2	1200	20	4000	55	34.8073
3	1200	30	6000	66	36.3909
4	1400	10	4000	32	30.1030
5	1400	20	6000	80	38.0618
6	1400	30	2000	32	30.1030
7	1600	10	6000	77	37.7298
8	1600	20	2000	69	36.7770
9	1600	30	4000	59	35.4170

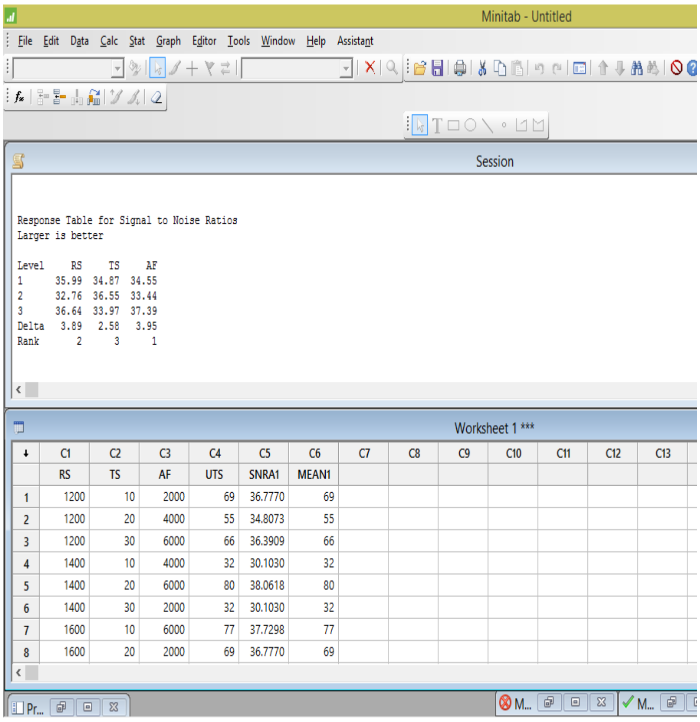

Fig.12 Mean and S/N ratio of tensile strength of FS Welds

Higher value of S/N ratio was selected for the input parameters. The optimum input parameter for friction stir welding joints are rotational speed 1600 (level 3), transverse speed 20mm/min and constant welding depth 5mm. the S/N ratio was directly found on MINITAB 17.

6.3 Taguchi Design :

Taguchi Orthogonal Array Design
L9 (3^3)
Factors: 3
Runs: 9
Columns of L9 (3^4) Array
1 2 3

Taguchi Analysis: tensile strength versus rotational speed, transverse speed

Larger is better

Table 6 Response Table for Signal to Noise Ratios

Level	**RS**	**TS**	**AF**
1	35.99	34.87	34.55
2	32.76	36.55	33.44
3	36.64	33.97	3739
Delta	3.89	2.58	3.95
Rank	2	3	1

Table 7 Response Table for Means

Level	**RS**	**TS**	**AF**
1	63.33	59.33	56.67
2	48.00	68.00	48.67
3	68.33	52.33	74.33
Delta	20.33	15.67	25.67
Rank	2	3	1

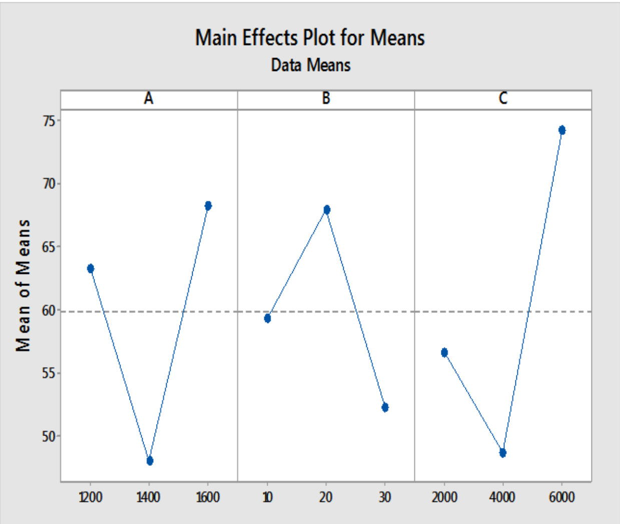

Fig.13 Main Effect Plot For SN Ratio

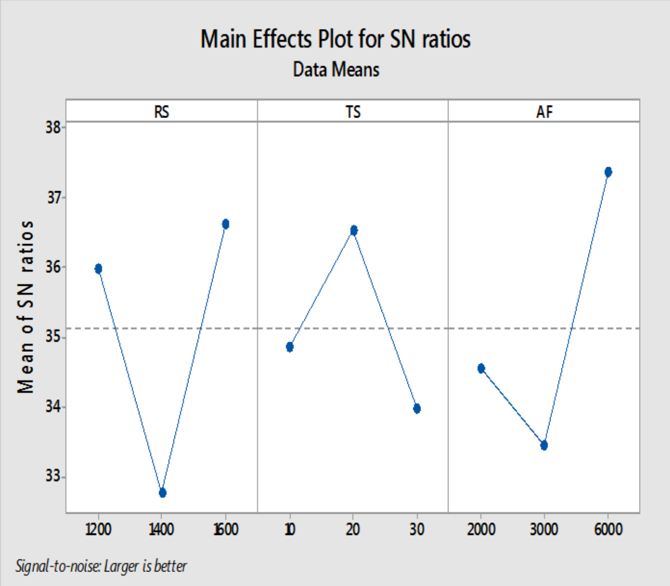

Fig.14 Main Effect Plot For Mean

6.4. Analysis Of Variance (ANOVA)

Analysis of variance (ANOVA) test was performed to identify the average performance of process parameters that are statistically significant. The ANOVA test is to investigate the significance of the process parameters which affect the tensile strength of FSW joints. The ANOVA results for tensile strength of means and S/N ratio are given in Table 4. In addition, larger F-value indicates the variation of process parameters makes big change on performance. The Smaller p-value, greater the significance of the process parameter.

Table 8 Analysis of Variance for SN ratios

Source	D F	Seq SS	Adj SS	Adj MS	F	P
Rotation al Speed	2	25.9 9	25.9 9	12.99 4	2.1 8	0.31 4
Transver se Speed	2	10.2 8	10.2 8	5.138	0.8 6	0.53 7
Axial Force	2	24.9 2	24.9 2	12.46 2	2.0 9	0.32 3
Error	4	11.9 1	11.9 1	5.955		
Total	8	73.1 0				

Table 9 Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Rotational speed	2	673.6	673.6	336.8	1.67	0.374
Transverse speed	2	369.6	369.6	184.8	0.92	0.522
Axial Force	2	1034.9	1034.9	517.4	2.57	0.280
Error	4	402.9	402.9	201.4		
Total	8	2480.9				

Table.10 Optimized result obtained from ANOVA – Minitab

	Rotational Speed in Rpm	Transverse Speed in mm/Min	Axial Force in N
Taguchi Method	1600	20	6000

6.5 Regression Analysis:
Regression Equation
UTS = 31.7 + 0.0125 RS + 0.00442 AF - 0.350 TS
Where, UTS is the response in terms of ultimate tensile strength and RS, TS is input parameters.
If we put optimum parameters which are drawn by ANOVA in equation it will give optimum value of quality characteristics which will maximum tensile strength.

UTS = 31.7 + 0.0125* RS + 0.00442* AF - 0.350* TS
UTS = 31.7 + 0.0125 *RS + 0.00442 *AF - 0.350 *TS
UTS= 71.22 Mpa predicted by regression equation.

6.6 Confirmation Testing:
Larger the better characteristic

S/N= -10 log10 (MSD)
MSD = $(1/Y1^2 + 1/Y2^2 + 1/Y3^2 + \ldots)/n$

Where Y1, Y2, Y3 are the responses and n is the number of tests in a trial and m is the target value of result. The level of a factor with the highest S/N ratio was the optimum level for responses measured.
In order to test the predicted result, confirmation experiment has been conducted by running three trials at the optimal setting of the process parameters determine from the analysis i.e. A3, B2, C3. Error between experimental valued and predicted valued by regression equation is 1.44 which is less than 5%'

Table 11Result of Average UTS & S/N Ratio

	Trial			UTS (Mpa)			S/N Ratio
	1	2	3	Experimental	predicted	% Error	
1	69	77	72	72.67	71.22	1.44	37.227

VII. CONCLUSION:

The following conclusions have been derived by applying TAGUCHI METHOD on the experimental investigations of AA 6082-T6 and AA 6082-T6 alloys by FSW.

1. The cylindrical tool with a tapered pin diameter have efficient stirring of the metal and efficient filling of the material in the gap formed during the welding process. Friction stir welding can apply successfully for aluminum alloy H30-H30 by CNC milling machine.

2. Friction stir welding window was developed to decide the range of tool rotational speed, travel speed and axial force.

3. The tensile strength increases with increase in the tool rotational speed and reaches maximum .The optimum value of process parameters such as rotational speed, traverse speed and axial force are found to be 1600rpm (level3), 20 mm/min (level 2) and 6000 N (level 3) respectively.

4. The Analysis of Variance for the tensile result concludes that the Rotational Speed is the most significant parameter with a percentage of 35.55 %, followed by the travel feed of 14.06 % and axial force 34.09%.

5. Friction stir welding is apply successfully for aluminum alloy H30-H30 by CNC milling machine.

6. The optimum value of process parameters such as rotational speed, traverse speed and welding depth are found to be 1400rpm (level 2), 20 mm/min (level 2) and 5mm (constant) respectively.

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