Study the Effect of Tool Pin Taper Variation on Impact Strength of AA 6351 Aluminium Alloy in FSW

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Abstract— Friction stir welding (FSW) is a new innovative solid state joining technique for joining similar and dissimilar metal which has been used in aerospace, rail, automotive and marine industries. The aim of this project is to optimize the effect of the tool shape and welding parameter on 10 mm thick AA6351 aluminums plates. The process parameters are optimized by using the TAGUCHI METHOD based on L9 orthogonal array. Experiments have been conducted based on three process parameters, namely, the tool rotation rate(rpm), welding speed and tool pin angle at three different levels. Impact Strength has been predicted for the optimum welding parameters and their percentage of contribution in producing a better joint is calculated.

Key words: Friction Stir Welding, Aa6351, Welding Parameter, Impact Strength, Signal-To Noise Ratio

I. Introduction

Friction Stir Welding (FSW) is a solid state welding process in which the relative motion between the tool and the work piece produces heat which makes the material of two edges being joined by plastic atomic diffusion. This method relies on the direct conversion of mechanical energy to thermal energy to form the weld without the application of heat from conventional source. The big difference between FSW and fusion welding (other than the lack of melting) is the ability to manipulate peak temperatures by choice of different welding parameters. Welding parameters, tool geometry, and joint design make use of considerable effect on the material flow pattern and temperature distribution, thereby influencing the micro structural evolution of material. [1] Also Tensile strength is higher with lower weld speed. This indicates that lower range of weld speed is suitable for achieving maximum tensile strength. [1] Friction stir welding of Al 6061- O condition, increases the strength of the weld joint as compared to that of the parent material in O-condition. Mechanical properties substantially improve during Post Weld Heat Treatment. [2] FSW offers a quality advantage that leads the welds strength and ductility either identical or better than that of the base metal alloy [3]. Tensile strength of FSW welds is directly proportional to the travel / welding speed [4]. The tensile strength of the FS welded is affected by the tool pin profile.

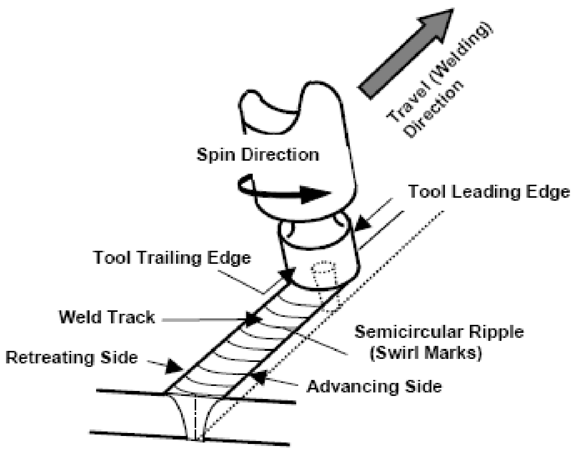

Fig. 1: Terminologies of Friction Stir Welding

II. Selection of Material

Aluminum Alloy AA6351: Aluminum alloy AA6351 is a medium Strength alloy with excellent corrosion Resistance. It has the highest strength of the 64430 series alloys. Alloy AA6351 is known as a structural alloy.

	Std-value	Result (%)
Silicon	0.60-1.30	0.790
Copper	0-0.10	0.075
Magnesium	0.40-1.20	0.553
Zinc	0-0.10	0.053
Iron	0-0.60	0.196
Manganese	0.40-1.00	0.454
Chromium	0-0.25	0.008
Titanium	0-0.20	0.016
Aluminium	Balance	97.797

Table 1 Chemical Composition of Aluminium Alloy AA6351

In plate form, AA6351 is the alloy most commonly used for machining. . The addition of a large amount of manganese controls the Grain structure which in turn results in a stronger alloy.

BASE MATERIAL	AA6351
Density(x1000kg/m3)	2.6-2.8
Elastic modulus(Gpa)	70-80
Tensile strength((Mpa)	250
Yield strength(Mpa)	150
Hardness(HB500)	95

Table - 2 Physical Characteristic of Aluminium alloy AA6351

III. Tool Design

Tool design influences heat generation, plastic flow, the power required, and the uniformity of the welded joint. The shoulder generates most of the heat and prevents the plasticized material from escaping from the work–piece, while both the shoulder and the tool pin affect the material flow. In recent years several new features have been introduced in the design of tools.

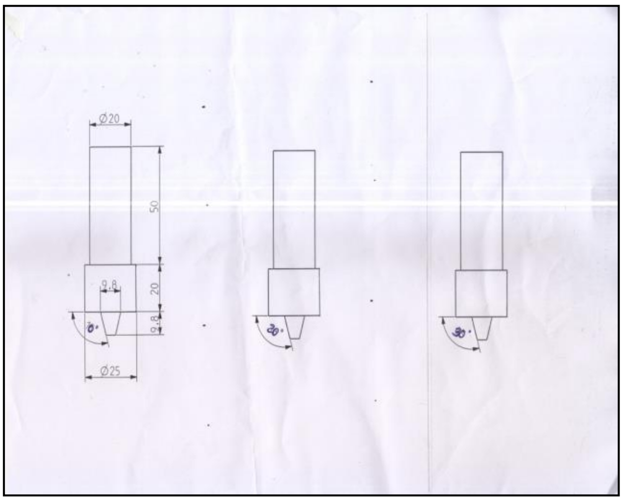

Fig. 2: Tool Design

Three various FSW tools are designed by varying the tool pin profile. The configurations of the designed FSW tool is:

A. *Tool pin profiles of Cone:*

Out of various tool materials like Tool steel, High Speed Steel (HSS), High Carbon High Chromium steel, carbide and carbon boron nitride, among which HSS steel is chosen as tool material because of its high strength, high hot hardness, easy to process, easily available and low cost. The FSW tools are manufactured using CNC Turning center and wire cut EDM (WEDM) machine. The tools are oil hardened to obtain a hardness of 60– 62 HRC.

Fig. 3: Tool Manufacturing

IV. WELDING PROCEDURE

The rolled plates of 10 mm thickness, AA 6351 Aluminium alloy, were cut into required size (100 mm x 50mm) by power hacksaw cutting and milling. Square butt joint configuration (100 mm x 100 mm) was prepared to fabricate FSW joints. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction single pass welding procedure was followed to fabricate the joints. Non-consumable tool, made of HSS were used to fabricate the joints. Three different tool pin profiles were prepared from HSS material and they were used to fabricate the joints but 25 mm shoulder was maintained for all the pin profiles. The most predominant factors which are having greater influence on tensile strength of friction stir welded Aluminium alloys are the tool pin profile, tool rotational speed, welding (traverse) speed and axial (downward) force. Trial experiments were conducted to determine the working range of the above factors.

V. PROCESS PARAMETER

A. *Input Parameters:*

1) Spindle speed
2) Feed rate
3) Tool pin taper (cylindrical)

B. *Output Parameters:*

1) Impact strength

Parameter	Factor	Level		
		1	2	3
Rotational speed in rpm	A	710	1000	1400
Tool pin angle in degree	B	10	20	30
Travel speed in mm/min	C	25	31.5	40

Table 2 Factor and Level of the Process Parameter

VI. TAGUCHI METHOD

The Taguchi Method is a multi-stage process, namely, systems design, parameter design, and tolerance design. The Taguchi method is used to improve the quality of products and processes. In Taguchi's approach, optimum design is determined by using design of experiment principles, and consistency of performance is achieved by carrying out the trial conditions under the influence of the noise factors. Taguchi defines three categories of quality characteristics in the analysis of Signal/Noise ratio, i.e. the lower-the-better, the larger-the-better and the nominal-the-better. The S/N ratio for each of process parameter is computed based on S/N analysis. Regardless of the category of the quality characteristics, a larger S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of process parameter is the level of highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) has been performed to see which process parameter is statistically significant for each quality characteristics and its relative contribution on the total performance.

The Taguchi method is very effective, because it is simple to carry on the experimental design and its approach is very systematic to provide good quality and low cost in manufacturing (Demirci et al., 2011). The main aim of the Taguchi method is to analyze the statistical data, which has been given as an input function to produce an optimum result. The effect of the combination of the input functions as a result is produced by the S/N ratio and mean response (Wu et al., 2002). The strength of the weld is varied by the parameters such as the tool rotating speed, tool tilt angle, depth of tool penetration, dwell time and travel speed.

VII. SELECTION OF ORTHOGONAL ARRAY

The experimental design proposed by ANOVA involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies.

Instead of having to test all possible combinations like the factorial design, the ANOVA techniques tests pairs of combinations. According to the L9 orthogonal array, three experiments in each set of process parameters have been performed on AA 6351 plates. The three factors used in this experiment are the rotation rate (rpm), welding speed and tool pin angle. The factors and the levels of the process parameters are presented in Table.3 and these parameters are taken based on the trials to weld the FSW of steels.(4)

Experiment run	Level		
	A	B	C
01	1	1	1
02	1	2	2
03	1	3	3
04	2	1	2
05	2	2	3
06	2	3	1
07	3	1	3
08	3	2	1
09	3	3	2

Table 3 L9 Orthogonal Array

VIII. EXPERIMENTAL PROCEDURE

A conventional milling machine can be successfully modified in to a Friction Stir Welding machine which is capable of producing defect free aluminum welds. During the welding of Al alloy 6351, the rotational speed of the tool is 710, 1000, and 1400 rpm. The Transverse feed rate for all the weld is 25, 31.5 and 40 mm/min. and tool pin angle 10, 20, and 30 degree. Figure 5 shows the welded plats of Al alloy 6351 which are weld by the taper tool.

Fig. 4: Welded plates of Al alloy 6351

X Testing, experimental result and analysis

After the welding impact test specimens are made by performing the machining on the welded plates. The impact specimens are made and testing is carried out according to the ASME SECTION-9.Figure 8 shows the impact test specimen.

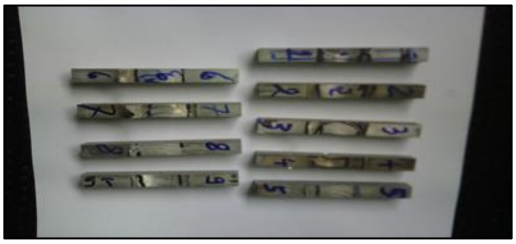

Fig. 5: Impact Test Specimen

Friction stir welding have been performed on AA6351 and AA6351 similar aluminium alloy metals by using vertical machining center according to TAGUCHI Orthogonal L9 Array. The experimental values for Impact Strength are shown in Table-4.

experiment notation	Input parameter			Impact strength (joules)
	A	B	C	
A1	710	10	25	36
A2	710	20	31.5	8
A3	710	30	40	10
B1	1000	10	31.5	14
B2	1000	20	40	26
B3	1000	30	25	14
C1	1400	10	40	4
C2	1400	20	25	10
C3	1400	30	31.5	8

Table 5: Experimental Data of Mechanical Property

s/n ratio analysis

Impact Strength values are analysed using Taguchi S/N ratio analysed by applying larger is better as quality character.

The Signal-To-Noise ratio for the bigger-the-better is:

S/N = -10*log (mean square of the inverse of the response).

S/N =-10log10(1/nE1/y2)

Where n = number of repetitions, y = response of impact strength

The experimental results were then transformed into signal-to-noise (S/N) ratio. In this work, S/N ratios were calculated and for each process parameter, signal-to-noise(S/N) ratio is given intable.

Level	Speed	Pin angle	Feed
1	23.06	22.03	24.68
2	24.71	22.12	19.68
3	16.70	20.33	20.11
Delta	8.01	1.79	5.00
Rank	1	3	2

Table 6: S/N Responses for Impact Strength

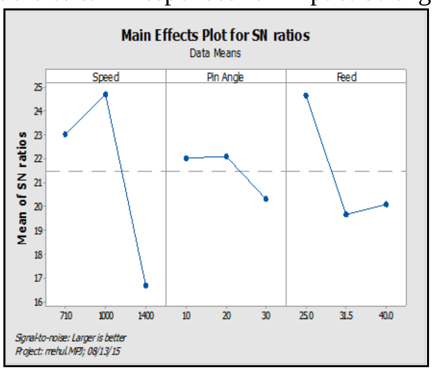

Fig. 6: Main Effect Plot For S/N Ratio For Impact Strength

From fig 6, the optimum parameter values are found at tool rotational speed 1000 rpm, pin angle 10 degree, feed 25mm/min for impact strength.

IX. CONCLUSION

The result obtained in this study lead to conclusions for welding of aa6351 material after analyzing the collect data. Using Taguchi method, the optimal process parameter of friction stir welded joints of aluminium alloy for impact strength is determined. And the most influence of process parameter on mechanical properties of friction stir welded joints of al alloy (AA6351) is found. The optimum combination of parameters obtained from the main effect plot for mean is process parameters of 1000 rpm tool Rotation rate (rpm), 25 mm/min welding speed and tool pin angle 10 degree has been predicted to give the better Impact Strength. To select an appropriate orthogonal array for experiments, the total degrees of freedom need to be computed.

The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is.

For example, a three-level process parameter counts for three degrees of freedom. The degrees of freedom associated with interaction between two process parameters are given by the product of the degrees of freedom for the two process parameters

Basically, the degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. In this study, an L9 orthogonal array was used.

A total of nine experimental runs must be conducted, using the combination of levels for each control factor as indicated in Table.

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