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Effect of Friction Stir Welding on Mechanical Properties of Dissimilar Aluminium Aa6061 and Aa2014 Alloy Joints

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Abstract

In present study, Dissimilar Friction Stir Butt Welds made of 2014 and 6061 Aluminium alloys were performed with various welding parameter. The present study deals with the influence of Square Profile Pin on Friction Stir Welded joint. FSW parameter such as Tool Rotational Speed, Welding Speed and Axial Force plays a significant role in the assessment of mechanical properties. Using ANOVA and Signal to Noise ratio, influence of FSW process parameters is evaluated and optimum welding condition for maximizing mechanical properties of the joint is determined. An Artificial Neural Network (ANN) model was developed for the analysis and simulation of the correlation between the Friction Stir Welding (FSW) parameters of aluminium (Al) plates and mechanical properties and compared the experimental values with the ANN predicted values.

Keywords: FSW, S/N Ratio, ANOVA, ANN, Dissimilar alloys..

Introduction

Friction stir welding (FSW) was invented at The Welding Institute (TWI) of UK in 1991 as a solid-state joining technique, and it was initially applied to aluminium alloys. The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint (Figure-1). The tool serves two primary functions: (a) heating of work piece, and (b) movement of material to produce the joint. The heating is accomplished by friction between the tool and the work piece and plastic deformation of work piece. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. As a result of this process a joint is produced in 'solid state'. FSW is considered to be the most significant development in metal joining in a decade and is a''green'' technology due to its energy efficiency, environment friendliness, and versatility. As compared to the conventional welding methods, FSW consumes considerably less energy. No cover gas or flux is used, thereby making the process environmentally friendly. The joining does not involveany use of filler metal and therefore any aluminium alloy can be joined without concern for thecompatibility of composition, which is an issue in fusion welding.

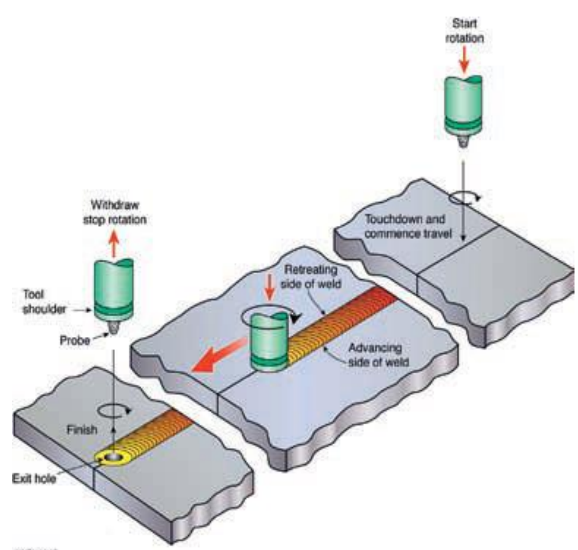

Figure-1: Principle of the Friction Stir Welding process for overlap joint configuration

Experimental Procedure and Methodology

The Methodology for Joint Considered in FSW process consists of AA6061 and AA2014 Al

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Alloy of 6.35mm thickness plate (150mm x 75 mm). The chemical composition and mechanical properties of AA 6061 and AA 2014 are shown in table-1 and table-2 respectively. Friction Stir Welding (FSW) was carried out according to the following sequence.

Table 1: Chemical composition of aluminium 6061 and 2014 alloys (weight %)

ELEMENT	AA6061	AA2014
Al	95.50	93.50
Cu	0.40	4.40
Mg	0.15	0.50
Si	0.80	0.80

Table -2: Mechanical properties of AA 6061 and AA 2014

MECHANICAL PROPERTY	AA6061	AA2014
Yield strength (MPa)	276	97
Ultimate Strength (MPa)	310	185
Elongation (%)	18	13
Reduction in cross sectional area(%)	12.24	15
Hardness (RHN)	105	45

Work pieces were a butted along a longitudinal section and rigidly on the thick backing plate, which was mechanically fixed on the bed of a Vertical Machining Centre (VERTIMACH V-350 VMC). Square Profile Pin Tool shown in Figure-2 rotated anticlockwise and vertically inserted into the work piece.

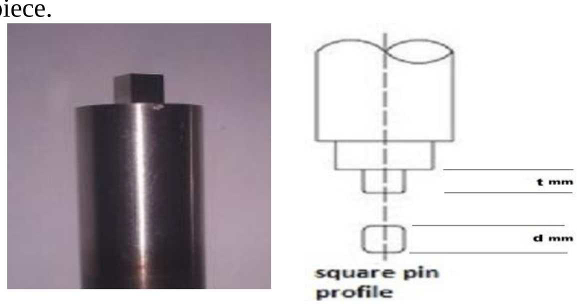

Figure-2: Square Profile Pin Tool

After entry of the pin to almost the thickness of the material and to allow the tool shoulder to just penetrate into the work pieces, the tool is transitioned along the joint line. The rotating tool develops frictional heat to the material, causing the metal to plasticize and produce a high integrity weld. The process parameters like rotational speed, welding speed and axial force play a significant role in assessment of mechanical properties of the joints and process parameters in present study is shown in Table-3.

Table-3: Process parameters and their levels

Process	Range	Level 1	Level 2	Level 3
Tool rotational speed (N), rpm	1200-2000	1200	1600	2000
Welding speed (S), mm/min	48-72	48	60	72
Axial force (F), KN	1.5-2.5	1.5	2	2.5

Similarly the experiment is repeated to join the remaining pieces by varying the process parameters as per design of TAGUCHI Orthogonal L27 Array. Further, Analysis of welded joints is to be found by conducting Tensile test on UTM, Impact test on Charpy Impact testing machine and Rockwell Hardness test on Rockwell Hardness Tester.

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.

Artificial Neural Network

Artificial Neural Networks (ANNs) are information, processing systems, and can be used in several areas of engineering applications and eliminate the limitations of the classical approaches by extracting the desired information using the input data. For predicting the mechanical properties a mathematical model is created using ANNs which represents the mechanical properties in terms of input parameters. The advantage of the use of ANN for prediction is that they are able to learn from examples only and when learning is finished, they are able to catch hidden and strongly non-linear dependencies, even when there is a significant noise in the training set.A standard feed forward neural network (FFNN) consisting of three layers viz. input, hidden and output layers and with an arbitrary activation function is a universal approximator. Figure-3 shows input layers, hidden layers and output layers architecture of the model.

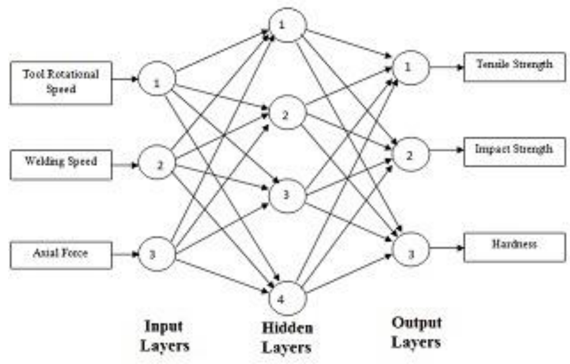

Figure-3: ANN architecture used

Results and Discussions

Friction stir welding have been performed on AA6061 and AA2014 dissimilar aluminium alloy metals by using vertical machining centre according toTAGUCHI Orthogonal L27 Array. The experimental values for tensile Strength, Impact Strength and Hardness are shown in Table-4.

Table-4: Experimental data of Mechanical Properties

S. No	Tool Rotational Speed (N) in r.p.m.	Welding speed (S) in mm/min	Axial Force (F) in KN	Tensile Strength (TS) in MPa	Impact strength, KN/mm^2	Hardness (RHN)
1	1200	48	1.5	210	710.5	26
2	1200	48	2	215	736.3	29
3	1200	48	2.5	223	1980.9	27
4	1200	60	1.5	212	705.1	29
5	1200	60	2	220.5	735	30
6	1200	60	2.5	226	1300.2	28
7	1200	72	1.5	211	224.1	30
8	1200	72	2	213.4	248.4	29
9	1200	72	2.5	216	260.6	27
10	1600	48	1.5	245	550	26
11	1600	48	2	250	575.8	25
12	1600	48	2.5	254	590.3	26
13	1600	60	1.5	243	690.4	29
14	1600	60	2	256	705.4	25
15	1600	60	2.5	263	737.5	28
16	1600	72	1.5	226	483.6	24
17	1600	72	2	238	510.8	27
18	1600	72	2.5	243	485	25
19	2000	48	1.5	228	489	27
20	2000	48	2	232.1	582.1	27
21	2000	48	2.5	241	682.6	29
22	2000	60	1.5	231	735	29
23	2000	60	2	240	842.9	28
24	2000	60	2.5	251	931.6	26
25	2000	72	1.5	217	865.2	25
26	2000	72	2	225	510.7	28
27	2000	72	2.5	232	523.2	31

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S/N Ratio Analysis

Tensile Strength, Impact Strength and Hardness 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).

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum\frac{1}{y^2}\right)$$

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

Theexperimental 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 in three levels is given in Table-5, table-6 and table-7.

Table-5: S/N responses for Tensile Strength

LEVELS	N	S	F
1	46.70	47.33	47.02
2	**47.83**	**47.51**	47.30
3	47.34	47.01	**47.54**
Delta	1.13	0.50	0.52
Rank	1	3	2

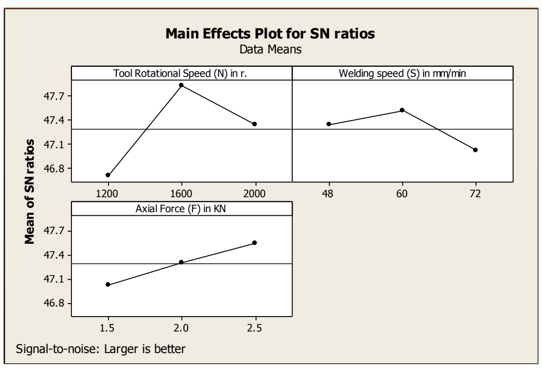

Figure-4: main effects plot for S/N Ratios for Tensile Strength

From Figure-4, the optimum parameter values are obtained at Tool Rotation speed(N) 1600 rpm, Welding speed (S) 60 mm/min, Axial Force (F) 2.5 KN for Tensile Strength.

Table-6:S/N responses for Impact Strength

LEVELS	N	S	F
1	55.57	56.83	55.13
2	55.35	**58.10**	55.21
3	**56.47**	52.45	**57.05**
Delta	1.13	5.65	1.93
Rank	3	1	2

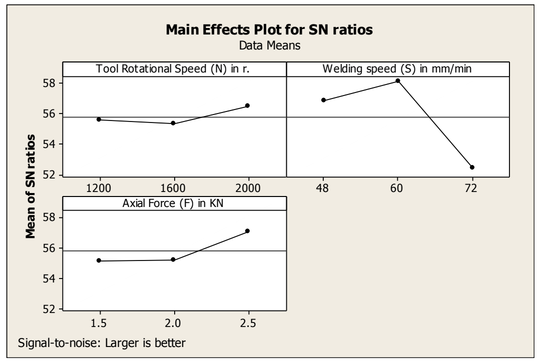

Figure-5: main effects plot for S/N Ratios for Impact Strength

From Figure-5, the optimum parameter values are found at Tool Rotation speed (N) 2000 rpm, Welding speed (S) 60 mm/min, Axial Force (F) 2.5 KN for Impact Strength.

Table-7: S/N responses for Hardness

LEVELS	N	S	F
1	**29.04**	28.58	28.68
2	28.32	**28.93**	**28.79**
3	28.86	28.70	28.75
Delta	0.71	0.35	0.11
Rank	1	2	3

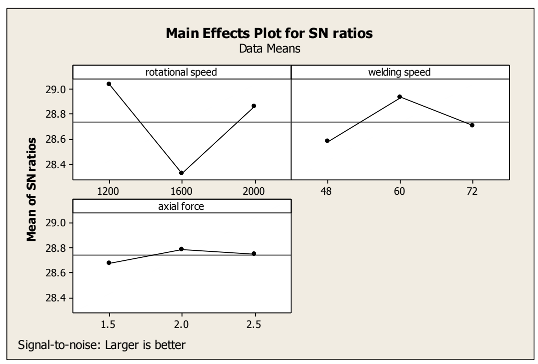

Figure-6: main effects plot for S/N Ratios for Hardness

From Figure-6, the optimum parameter values are found at Tool Rotation Speed(N) 1200rpm, Welding Speed (S) 60 mm/min, Axial Force (F) 2.0 KN for Hardness.

ANOVA Results

The results of ANOVA on the Tool rotation speed (N), Welding speed(S), Axial Force (F) and influence of process parameters on Tensile Strength, Impact Strength and Hardness are determined by using MINITAB and is shown in table-8, table-9 and table10-.

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General Linear Model

Factors	Type	Levels	Values
Tool rotational speed (N)	Random	3	1,2,3
Welding speed (S)	Random	3	1,2,3
Axial force (F)	Random	3	1,2,3

ANOVA Results for Tensile Strength

From the Table-8, the Percentage Contribution of values for Tool Rotational Speed (67.30), Welding Speed (13.69) and Axial Force (14.50) is shown. It is observed that the Tool Rotational Speed have great influence on Tensile Strength.

ANOVA Results for Impact Strength

From the Table-9, the Percentage Contribution of values for Tool Rotational Speed (4.55), Welding Speed (22.89) and Axial Force (10.20) is shown. It is observed that the Welding Speed have great influence on Impact Strength.

ANOVA Results for Hardness

From the Table-10, the Percentage Contribution of values for Tool Rotational Speed (27.825), Welding Speed (6.507) and Axial Force (0.599) is shown. It is observed that the Welding Speed have great influence on Hardness

Table-8: ANOVA results for TENSILE STRENGTH

FACTOR	DEGREES OF FREEDOM DOF=(LEVELS-1)	SUM OF SQUARES (SS)	MEAN SQUARES (MSS)	PERCENTAGE OF CONTRIBUTION
N	2	4098.97	2049.48	**67.30**
S	2	834.05	417.03	**13.69**
F	2	883.19	441.59	**14.50**
RES	20	273.87	13.69	4.51
TOTAL	**26**	**6090.07**		**100**

Table-9: ANOVA results for IMPACT STRENGTH

FACTOR	DEGREES OF FREEDOM DOF=(LEVELS-1)	SUM OF SQUARES (SS)	MEAN SQUARES (MSS)	PERCENTAGE OF CONTRIBUTION
N	2	137506	68753	**4.55**
S	2	692584	346292	**22.89**
F	2	308797	154399	**10.20**
RES	20	1887411	94371	62.36
TOTAL	**26**	**3026299**		**100**

Table-10: ANOVA results for HARDNESS

FACTOR	DEGREES OF FREEDOM DOF=(LEVELS-1)	SUM OF SQUARES (SS)	MEAN SQUARES (MSS)	PERCENTAGE OF CONTRIBUTION
N	2	24.074	12.037	**27.825**
S	2	5.630	5.630	**6.507**
F	2	0.519	0.519	**0.599**
RES	20	56.296		65.067
TOTAL	**26**	**86.519**		**100**

Comparison of ANN predicted values with Experimented values for Mechanical Properties:

Table-11: Experimental values and ANN Predicted values

Levels	Experimental Tensile Strength values	ANN Predicted Tensile Strength	Experimental Impact Strength values	ANN Predicted Impact Strength Values	Experimental Hardness values	ANN Predicted Hardness values
1	210	211.7	710.5	713.4	35	35.35
2	215	215.4	736.3	738.5	29	29.35
3	223	222.6	1980.9	1978.4	27	27.70
4	212	212.9	705.1	705.4	33	31.51
5	220.5	219.2	735	731.3	25	27.93
6	226	226.6	1300.2	1298.9	28	26.86
7	211	211.5	224.1	229.9	30	32.12
8	213.4	213.7	248.4	243.1	37	33.21
9	216	216.1	260.6	263.3	27	30.47
10	245	244.8	550	551.4	32	31.40
11	250	250.2	575.8	568.1	33	32.63
12	254	254.4	590.3	592.4	36	35.05
13	243	243.0	690.4	689.2	31	31.60
14	256	256.3	705.4	705.7	25	29.30
15	263	260.2	737.5	744	33	30.78

16	226	226.2	483.6	481.4	36	33.44
17	238	237.5	510.8	508.6	32	31.03
18	243	243.3	485	486.5	33	31.03
19	228	228.5	489	481.2	31	33.05
20	232.1	231.5	582.1	595.6	39	36.79
21	241	241.3	682.6	679	40	38.60
22	231	230.8	735	740	35	32.36
23	240	240.0	842.9	838.1	32	32.01
24	251	251.3	931.6	929.4	32	33.34
25	217	217.2	865.2	863.7	25	29.12
26	225	224.9	510.7	513.5	28	27.74
27	232	232.1	523.2	522	29	29.57

The predicted values and experimental values for L27 orthogonal array are shown in Table-11 and show the comparison of results between experimental and predicted Hardness values. It is clear that the proposed model can predict the values which are nearly very close to experimental observations for each of the output parameters.

Conclusion

The results obtained in this study lead to conclusions for welding of AA6061 and AA2014 dissimilar aluminium alloy materials after analyzing the collected data.

- Using Taguchi method, the optimal process parameters of Friction Stir Welded joints of Dissimilar Aluminium Alloys for Tensile Strength, Impact Strength and Hardness is determined. And the most Influence of process parameter on mechanical properties of friction stir welded joints of dissimilar Al alloys (AA 6061 and AA 2014) is found.
- Using analysis of variance (ANOVA), the percentage of contribution for Rotational Speed, Welding Speed and Axial Force on Tensile Strength, Impact Strength and Hardness is determined.
- ANN model has been developed for prediction of Tensile Strength, Impact Strength and Hardness as functions of welding process parameters. The model has been proved to be successful in terms of agreement with experimental results.

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