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STATISTICAL ANALYSIS OF FRICTION STIR WELDED AA 5052-H34 WELDMENTS BY APPLYING TAGUCHI TECHNIQUE

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ABSTRACT

Friction stir welding (FSW) process is a promising solid state joining process with the potential to join low melting point materials below re-crystallization temperature. The most attractive reason for this is the avoidance of solidification defects formed during conventional fusion welding processes. The present work aims to evaluate the effect of welding parameters on the tensile properties of 2mm thin sheet 5052-H34 aluminium alloy joints produced by friction stir welding. Taguchi method is a powerful technique for the design of high quality systems. This technique has been widely used in engineering design for its, efficient and systematic statistical approach to optimize design performance, quality and cost over a verity of conditions. The L9 orthogonal array has been used to design the experiments, and the experiments have been conducted in vertical milling machine. The main influencing parameters in FSW are tool rotational speed, traversing speed and pressure applied on the faying surfaces. After welding, the weld strength and percentage elongation have been evaluated using uniaxial tensile test. Based on the experimental data the results are then analyzed by using ANOVA statistical tools. This paper experimentally proves and suggests the optimized process parameter values to attain maximum tensile strength in butt joint configuration.

Keywords: friction stir welding, Taguchi technique, tensile strength, statistical approach, optimization.

INTRODUCTION

Friction Stir welding (FSW) is a solid-state joining process invented by TWI in 1991 that is presently attracting considerable interest and it has developed extensively for aluminium alloys, and also for magnesium, copper, titanium and steel [1-5]. FSW has wide application potential in ship building, aerospace, automobile, railway and other manufacturing industries [6]. However, the FSW process requires deep and complete understanding of the technological process and the achieved mechanical behaviour, in order to be considered for large scale production of industrial components [7]. FSW offers several advantages over conventional fusion welding processes due to its low heat input and absence of melting of solidification processes [3, 5]. FSW uses a rotating tool that consists of a shoulder and a pin.

The shoulder is pressed against the surface of the materials being welded, while the pin is forced between the two plates by an axial force. The rotation of the tool under this force generates a frictional heat that decreases the resistance to plastic deformation of the material. The softened material then easily moves behind the tool and forms a solid state weld. Compare to conventional fusion welding methods the advantages of the FSW process include better mechanical properties, low residual stress and distortion, and reduce occurrence of defects [1, 4]. This is due to the solid - state joining and the weld zone with fine worked or recrystallized grain structure generated by stirring and forging during FSW [8, 9]. The most important benefits of FSW are its ability to weld the materials that were thought of difficult to be welded such as aluminium alloys of 2xxx, 5xxx and 7xxx series [3, 5].Under the action of rotating nonconsumable tool the formation of defect free friction stir processed zone is affected by the material flow behaviour [10].It utilizes non consumable rotating tool to produce frictional heat and plastic deformation.[11] Researchers found that the tensile properties and fracture locations of the joints are significantly affected by the welding process parameters. HAN *et al* [12] investigated the optimum conditions for FSW of AA5083-O aluminium alloy by evaluating the mechanical characteristics. Leal and LOUREIRO [13] studied the effect of the weld travel speed on the defect formation on the changes in the microstructure and on the mechanical properties of weld in aluminium alloys. The single pass joints of various alloys welded using FSW are stronger when compared with the traditional riveted and resistance spot welded joints [14]. Elatharasan. G *et al* [15] studied the effect of FSW welding parameters on the ultimate tensile strength (UTS), Yield strength (YS) and % Elongation (%E) of AA6061-T6 aluminium alloy. Lakshminarayanan *et al.* [16] investigated the optimum joints of FSW parameters to attain maximum tensile strength of AA7039 joints using Taguchi parametric design approach. Biswajit Parida *et al.,* [17] described the effect of tool geometry on tensile strength and distribution of microhardness in different zones of FSW weld specimen. Though various aluminium joints produced by FSW were investigated and studied by several researchers, optimization of FSW process parameter of aluminium alloy AA 5052-H34 2mm thickness sheet has not yet studied. Therefore an attempt has been made to attain three output responses UTS, YS and %E in order to identify the optimal operating parameters.

EXPERIMENTAL PROCEDURE

In this investigation the material used for experiment was AA5052-H34. The elemental compositions of working sheet metals are presented in Table-1. The rolled sheets of 2mm thickness were

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machined to the required dimensions of 100mm x50mm and FSW was carried out in butt joint configuration using a column type vertical milling machine. The welding direction was aligned normal to the rolling direction; the single pass welding procedures are used to fabricate the joints. The photographs of the welded joints are displayed in Figure-1. Nonconsumable tool of 12 mm shoulder diameter, 4mm pin diameter and 1.8mm pin length of HSS M35 Grade cylindrical pin profile was used. The tensile specimens from the welded samples were cut transverse to the welding direction. The subsize tensile specimens were prepared as per ASTM E8/E8M (2012) guidelines [18]. The weld specimens were cut using 'wire EDM' machine its dimensions are shown in Figure-2 and the photograph is displayed in Figure-3.

After a number of trial experimental runs the process parameters affecting the tensile strength were identified as tool rotational speed (N), welding speed (S) and shoulder plunge depth (P) and keeping rest of them at constant values. The selected process parameters and their levels are presented in Table-2.

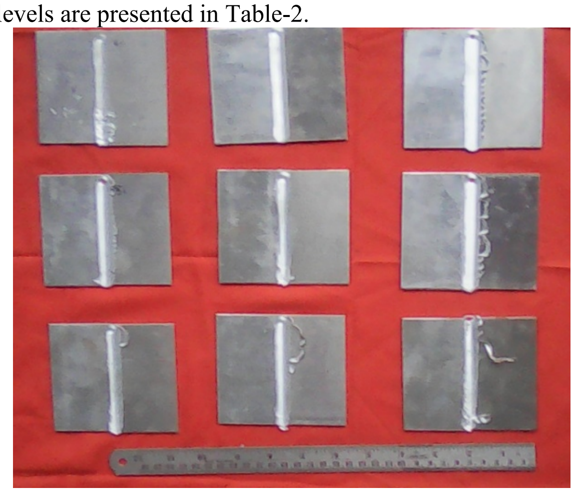

Figure-1. Photograph of welded joints.

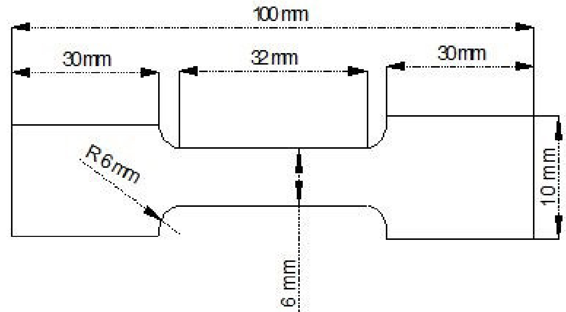

Figure-2. The tensile test specimen.

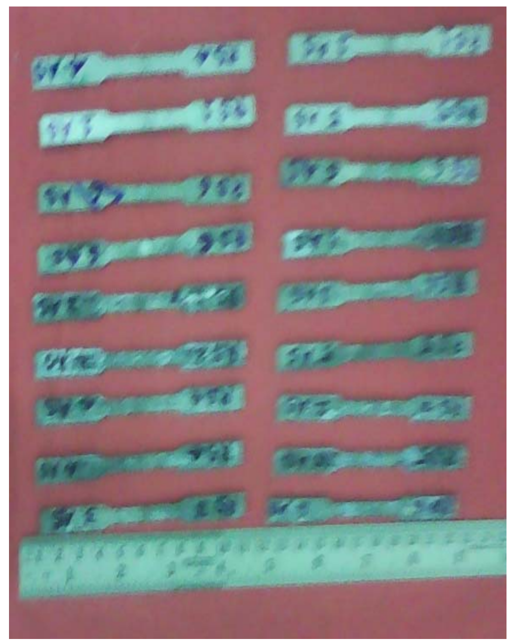

Figure-3. Photograph of tensile specimen.

Table-1. Elemental composition (Wt %) of base metal.

Material	Si	Fe	Cu	Mn	Mg	Cr	Zn	Sn	Ni	Ti	Al
AA5052-H34	0.231	0.466	0.056	0.034	2.690	0.172	0.125	0.115	0.012	0.014	Bal

Table -2. Process parameters and their levels.

Parameters	Notation	Level 1	Level 2	Level 3
Tool rotational speed	N (rpm)	1200	1400	1600
Welding speed	S (mm/min)	14	20	26
Plunge depth	P (mm)	0.08	0.10	0.12

TAGUCHI METHOD

Several numerical methods are widely used for either modeling or optimizing the performance parameters. The Taguchi method can be effectively used for optimizing process parameters to achieve high quality welds withoutincreasing the cost of experimentation. This method is insensitive to the variation in environmental conditions and noise factors. The Taguchi L9 orthogonal array design matrix is used for conduct experiments. Nine experiments were conducted as per L9 orthogonal array design matrix. The response variables UTS, YS and %E was tested using the analysis of variance (ANOVA) statistical technique [19]. They are also used to find the contribution of each parameter. F-test proposed by Fisher is used as an auxiliary tool of inspection. Thus, the larger the value of f-test the more dominant the parameters. The input process parameters, output responses and corresponding S/N ratio are presented in Table-3.

The loss function and S/N ratio is computed by using equation (1) and (2) respectively. Where L_{ij} is S/N ratio for larger the better, y_i is measured characteristics from experiments, n is number of experiments.

$$L_{ij} = \frac{1}{n}\sum \frac{1}{y_i^2} \quad (1)$$

$$N_j = 10\log_{10}(L_{ij}) \quad (2)$$

The analysis of S/N ratio is based on the criteria higher is the better is used to analyze and assess the performance characteristics. The noise is measured from the deviations obtained from the average responses which would reveal the sensitiveness to the noise factors.

RESULTS AND DISCUSSION

a) Effects of process parameters on ultimate tensile strength

Ultimate tensile strength or tensile strength is measured by the maximum stress that a material can withstand while being stretched or pulled before breaking. Thus it is taken larger the better to calculate S/N ratio which shows the ANOVA obtained in Table-4.

Figure-4 shows effects of S/N ratio and concluded that the rotational speed of 1600 r.p.m, welding speed of 20 mm/min and plunge depth of 0.12 mm gives the optimum machining condition for UTS.

From the Table-4 it is obtained that 54.25%, 30.60%, and 5.37% contribution of N, P and S respectively for higher UTS. The optimum process parameters can be found by response table and it is ranked rotational speed, plunge depth and welding speed in Table-5.

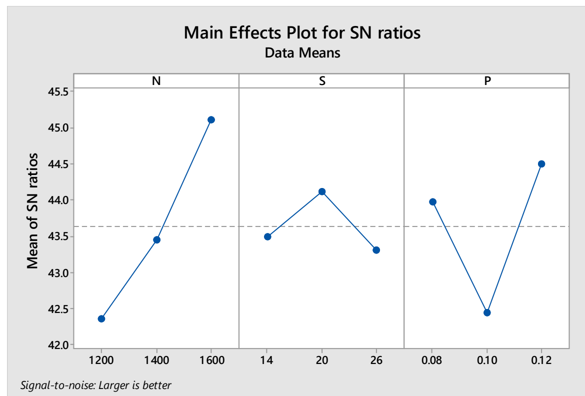

Figure-4. Main effect plot for UTS.

Table-3. Taguchi orthogonal array design matrix and responses.

Exp. No.	Tool Rotational Speed(N) rpm	Welding Speed (S) mm/min	Plunge Depth (P) mm	UTS N/mm²	YS N/mm²	%E	S/N ratio of UTS	S/N ratio of YS	S/N ratio of %E
1	1200	14	0.08	126	118	3.06	42.00	41.43	9.71
2	1200	20	0.10	129	123	3.20	42.21	41.79	10.10
3	1200	26	0.12	139	131	5.00	42.86	42.34	13.97
4	1400	14	0.10	127	121	3.13	42.07	41.65	9.91
5	1400	20	0.12	163	158	4.33	44.24	43.97	12.72
6	1400	26	0.08	159	156	3.06	44.02	43.86	9.71
7	1600	14	0.12	209	184	6.33	46.40	45.29	16.02
8	1600	20	0.08	197	161	5.67	45.88	44.13	15.07
9	1600	26	0.10	142	136	4.06	43.04	42.67	12.17

Table-4. Analysis of variance for ultimate tensile strength.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution, %
N	2	4060.2	2030.1	5.59	0.152	54.25
S	2	401.6	200.8	0.55	0.644	5.37
P	2	2296.2	1148.1	3.16	0.240	30.6
Error	2	726.2	363.1	–	–	9.70
Total	8	7484.2	–	–	–	–

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Table-5. Response table for mean UTS.

Level	N	S	P
1	131.3	154.0	160.7
2	149.7	163.0	132.7
3	182.7	146.7	170.3
Delta	51.3	16.3	37.7
Rank	1	3	2

b) Effects of process parameters on yield strength

A yield strength or yield point is the stress that a material begins to deform plastically. The yield point determines the limits of performance for mechanical components. It represents the upper limit to forces that can be applied without permanent deformation. Thus it is taken larger the better to calculate S/N ratio, shows the analysis of variance ANOVA in Table-6 for YS.

From the Table-6 it is obtained that 48.68%, 35.54%, 2% contribution of N, P, and S respectively for higher YS.

The optimum process parameters can be found by response table and it is ranked rotational speed, plunge depth and welding speed in Table-7.

Figure-5 concludes that tool rotational speed of 1600 rpm, welding speed of 20 mm/min and 0.12mm for obtaining optimized parameters for YS.

Figure-5. Main effect plot for YS.

Table-6. Analysis of variance yield strength.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution, %
N	2	1996.22	998.11	3.52	0.221	48.68
S	2	80.22	40.11	0.14	0.876	2.00
P	2	1457.56	728.78	2.57	0.280	35.54
Error	2	566.89	283.44	–	–	13.82
Total	8	4100.89	–	–	–	–

Table-7. Response table for mean yield strength.

Level	N	S	P
1	124.0	141.0	145.0
2	145.0	147.3	126.7
3	160.3	141.0	157.7
Delta	36.3	6.3	31.0
Rank	1	3	2

Table-8. Analysis of variance percentage elongation**.**

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution, %
N	2	6.0310	3.01551	6.55	0.132	49.76
S	2	0.1988	0.09938	0.22	0.822	1.64
P	2	4.9678	2.48388	5.40	0.156	41.00
Error	2	0.9207	0.46034	–	–	7.60
Total	8	12.1182	–	–	–	–

c) Effects of process parameters on percentage elongation

Within the gauge length, usually expressed as a percentage of the increase in the gauge length, measured after fracture of the specimen the original gauge length. The tensile specimen is pulled to failure and then fitted together at the fracture. The distances between corresponding markings straddling the fracture are measured extending progressively outward from the fracture. Thus it is taken larger the better to calculate S/N ratio, shows the analysis of variance ANOVA in Table-8 for percentage elongation.

From the Table-8 it is obtained that 40.76%, 41.00%, 1.64% contribution of N, P, and S respectively for higher tensile elongation.

The optimum process parameters can be found by response table and it is ranked rotational speed, plunge depth and welding speed in Table-9.

Table-9. Response table for mean percentage elongation.

Level	N	S	P
1	3.753	4.173	3.930
2	3.507	4.400	3.463
3	5.353	4.040	5.220
Delta	1.847	0.360	1.757
Rank	1	3	2

Figure-6 concludes that tool rotational speed of 1600 rpm, welding speed of 20 mm/min and 0.12mm for obtaining optimized parameters for YS.

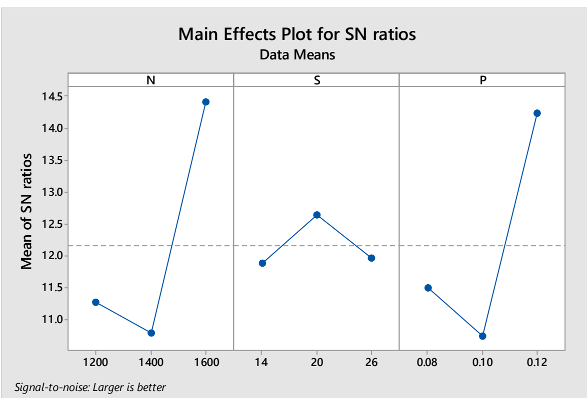

Figure-6. Main effect plot for % E.

CONCLUSIONS

In this study, a detailed investigation had been carried out to find out the impact of the optimized process parameters with a cylindrical pin profiled HSS M35 grade tool during the FSW of AA5052-H34.

The Taguchi technique was used to obtain the maximum UTS, YS, and %E. The analysis presents the effect of input variables such as tool rotational speed, welding speed and plunge depth. The ANOVA analysis showed that the developed statistical model can be effectively used to predict the maximum UTS, YS, and %E.

- Tool rotational speed was the major influence factor affecting the tensile strength, yield strength and tension elongation.
- UTS, YS and %E of the FS welded joints increased with the increase of tool rotational speed and applied pressure, but decreased by increasing of welding speed.
- A maximum tensile strength of 209 N/mm^2, yield strength of 184 N/mm^2 and tension elongation of 6.33 was exhibited by the FSW joints fabricated with the optimum parameters of 1600 rpm rotation speed, 14 mm/min welding speed and 0.12 mm plunge depth.

Finally, this investigation reveals that strength of the defect free welds can be improved and enhanced by selecting the optimized process parameters during the FSW of AA5052 H34 alloys.

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