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Optimization of FSW Process Parameters on Dissimilar Aluminium Alloy using Taguchi Method

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ABSTRACT: The basic principle of Friction stir welding (FSW) is heating the metal to a temperature below the re-crystallization temperature thus reducing the welding crack such as porosity band hot crack with are commonly formed in the conventional welding method due to alloy's low crystallization temperature and high heat dissipation nature. The quality of friction welding is good when compared to other fusion welding technique. The main influence parameter in FSW is rotational speed welding traversing speed and pressure applied against the joint. AA5083 and AA6061. Aluminium alloy has high strength to weight ratio. They have main application in the field of marine, aerospace and automobiles. As it is difficult to perform number of experiments to find out the level combinations which yield good mechanical properties like tensile strength, Taguchi L9 orthogonal array is used to reduce the number of experiment. The material is bought and are cut into specific material and polished. They are then welded based on the different experiment obtained from Taguchi method. After welding is done the metals are cut as per the specific standard. The results are then analysed by using ANOVA statistical tools. ANOVA table clearly shows the percentage of contribution of each factors can be determined. The best welding quality is found out by comparing the result obtained from tensile testing. Using UTM machine the tensile test was carried out.

KEYWORDS: Friction stir welding (FSW) ANOVA, Taguchi, Tensile Strength, POE.

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 faying 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. The welding parameters and tool pin profile play a major role in deciding the weld quality. AA6061 aluminium alloy has gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to-weight ratio. AA5083 aluminium alloy uses friction stir welding (FSW) process which is a solid-state joining process in which the material that is being welded does not melt and friction stir welding is a solid state joining process invented in TWI in Cambridge, England in 1991 firstly for joining aluminium alloys [1]. In aircraft and automotive structures friction stir welded lap joints have been widely used with the aim to replace riveted lap joints by using aluminium alloys from 2XXX to 7XXX series. Rivet holes are often potential sites for crack initiation or corrosion problems; moreover, the elimination of fasteners leads to considerable weight and cost savings. A few examples of FSW joints applied in automotive industries are some applications include engines, wheel rims and lap joints in car back supports [2-3]. Since, in FSW process, the joint is permanent a specially designed inconsumable rotating shouldered tool pin into the interface of two pieces of sheets and moving it along the weld line to heat and stir the sheets' materials by producing friction between the shoulder and the sheet surface and also the material flow by the pin movement. As the tool moves through the weld line, the heated materials of two sheets flow and mix together without melting and make the welded joint [4]. The kissing bond defect is resulted by insufficient heat transferred to the interface of sheets that leads to produce separated interfaces with remained oxide layers among them. This defect usually occurs at the retreating side because of its lower temperature during friction stir welding [5]. FSW the joining process is accomplished by material flow below the melting temperature, many joint defects caused by joint material melting such as porosity, grain boundary cracks and alloys segregation can be eliminated or adequately reduced. These process specialties have made FSW very practical for joining dissimilar alloys. Lately some researchers have been performed on friction stir welding of dissimilar aluminium lap joints [6, 7]. AA5083 is a strain hardening structural alloy that is widely used in aerospace, marine and military industries mostly because of its light weight, admissible weld ability and elite corrosion resistance



[8]. Some recent researches have studied friction stir welding of this aluminium alloy in similar or dissimilar joints [9-12]. The FSW joint is normally affected by a lot of parameters. Some important parameters are shape and geometry of the tool, tool tilt angle and also the rotational and welding speeds of the tool during the process. Tool rotational and welding speeds are two FSW critical parameters particularly for adjusting the welding temperature. Low welding temperature may produce insufficiently stirred sheet interface and cause many defects like kissing bonds and extremely high welding temperature may lead to unexpected joint microstructure or alloys melting.

II. METHODOLOGY

2.1 Experimental design

The parameters identified for investigation are tool rotation speed, welding speed, Tilt angle. The selected process parameter and their levels are shown in table 1. This is the design of experiment by which the works are done.

Table 1 process parameter and their levels.

Symbol	Drilling parameter	Level 1	level 2	Level 3
N	Tool rotation speed(rpm)		710	900 1120
S	Welding speed (mm/min)		50	60 70
D	Tilt angle(degree)	0		1 2

2.2 Taguchi's method

Taguchi's method is a tool for design of a high quality system. This method is a systematic approach for performance and quality optimization. By this method the number of experiment is reduced to 9. The total degree of freedom must be calculated to choose the correct orthogonal array. The degree of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. So, L9 orthogonal array was selected which has a degree of freedom of 8. Nine experimental runs were conducted as per Taguchi L9 orthogonal array.

2.3 ANOVA analysis

Analysis of Variance (ANOVA) is a statistical method which is used to discuss the relative importance of the entire control factor. 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 are.

2.4 S/N ratio

Taguchi also recommended to analyse the valued using S/N ratio. It involves conceptual approach which

III. EXPERIMENTAL PROCEDURE

Process Involved the following processes of operations were adopted while carrying out the Friction Stir Welding.

- Cutting,
- Job Preparation,
- Welding.
- Cutting:

The base metal sheets of dimensions 170 mm*60mm were cut by using shearing machine.

- Job Preparation:

Edges of sheared faces were grinded to get good finish and checked and ensured for perpendicularity. The initial joint configuration is securing the plates in position using mechanical clamps.

- Welding:

The direction of welding is normal to the rolling direction. Single pass welding procedures are used to fabricate the joints. Non-Consumable cylindrical tool is made up of high carbon steel. It is used to fabricate the joints. A non-consumable rotating tool is specially designed by pin and shoulder to insert into the abutting edges of sheets or plates to be joined and traversed along the line of the joint.

The primary functions of the tools are:

1. Heating the work piece
2. Movement of material to form joints

Plastic deformation of the work piece is achieved by the friction produced between the tool and the work piece. The high heat which is produce softens the material around the pin. The combined effect of tool rotation and translation leads to movement of materials from front to the back of the pin. Thus a “solid state” join is formed. During the friction stir welding process the material undergoes a plastic deformation at high temperature which results in generation of fine and equalled re-crystallized grains. Good mechanical properties of the work piece are due to the fine microstructure achieved through friction stir welding process. Since FSW has good energy efficiency, versatility and environmental friendliness thus they are considered to be a GREENtechnology. The experimental setup of FSW is shown in figure 1.



Figure 1 Friction stir weld on the dissimilar aluminium metal alloy

The stirring and mixing of materials around the rotating pin is done by the rotation of tools thus stirrers’ material from the front to the back of the pin and finishes the welding process. Since the tool rotates at high speed it generates high temperature because of higher friction heating and result in more intense stirring and mixing of material. Thus, increases in heat are directly proportional with the tool rotation rate is not expected as the coefficient of friction at interface will change with increasing tool rotation rate. Table 2 shows the different experiments conducted based on Taguchi’s L9 orthogonal array and the test results.

Table 2. Experimental Results

Ex. No	Tool Rotational Speed(N) r.p.m	Welding Speed(S) in (mm/min)	Tilt Angle(D) Degree	Tensile Strength	Yield Strength	POE(%)
c	710	50	0	158.943	141.1337.04	



2	710	60	1	171.583	152.5485.84
3	710	70	2	156.647134.77	6.34
4	900	50	1	124.74297.309	4.04
5	900	60	2	140.406	121.8577.04
6	900	70	0	171.933	151.7378.60
7	1120	50	2	174.660	153.6398.80
8	1120	60	0	135.443	105.3734.50
9	1120	70	1	180.571	158.7649.60

Ex.no	S/N ratio of UTS	S/N ratio of YS	S/N ratio of POE
1	44.02	42.9	16.95
2	44.68	43.66	15.32
3	43.89	42.59	16.04
4	41.92	39.76	12.12
5	42.94	41.71	16.95
6	44.70	43.62	18.69
7	44.84	43.72	10.28
8	42.63	40.45	13.06
9	45.13	44.01	19.64

IV. RESULT AND DISCUSSION

4.1 Ultimate tensile strength

Tensile strength or ultimate strength is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. The value of the test specimen does not depend on the size of the work piece but it depends on factors like surface finish, the temperature of the test environment etc. Tensile testing of material was carried out at ASTM A370. Thus, we need larger tensile strength to make the material withstand while stretched or pulled. Thus, we use Larger the better to calculate S/N ratio. Table 3 shows the ANOVA table for Tensile strength.

Table 3. ANOVA table for UTS

Source	Degree of freedom	Sum of squares	Mean of squares	F test	P test	Contribution(%)
N	2	599.4	299.7	0.72	0.52	19.41
W	2	723.2	361.6	0.92	0.449	23.43
D	2	18.66	9.329	0.02	0.982	0.6
Error	2	2193.26	440.05			
Total	8	3087.5				



From the table 3 we can clearly see that the combine contribution of tool tilt angle and tool rotation speed is much lesser than the welding speed. Welding speed has a major contribution of 23.43%. The optimum machining parameter can be found by response table which is shown in table 4.

Table 4 Response table for UTS

Level	Tool rotation speed	Welding speed	Tool tilt angle
1	44.0	43.6	43.75
2	43.19	43.42	43.91
3	44.2	44.58	43.90
Delta	1.01	1.18	0.13
Rank	2	1	3

From the table 4 and figure 2 it can be concluded that tool rotational speed of 1120 r.p.m, welding speed of 70 mm/min and tool tilt angle of 0 degree is the optimum machining condition to get a good ultimate tensile strength.

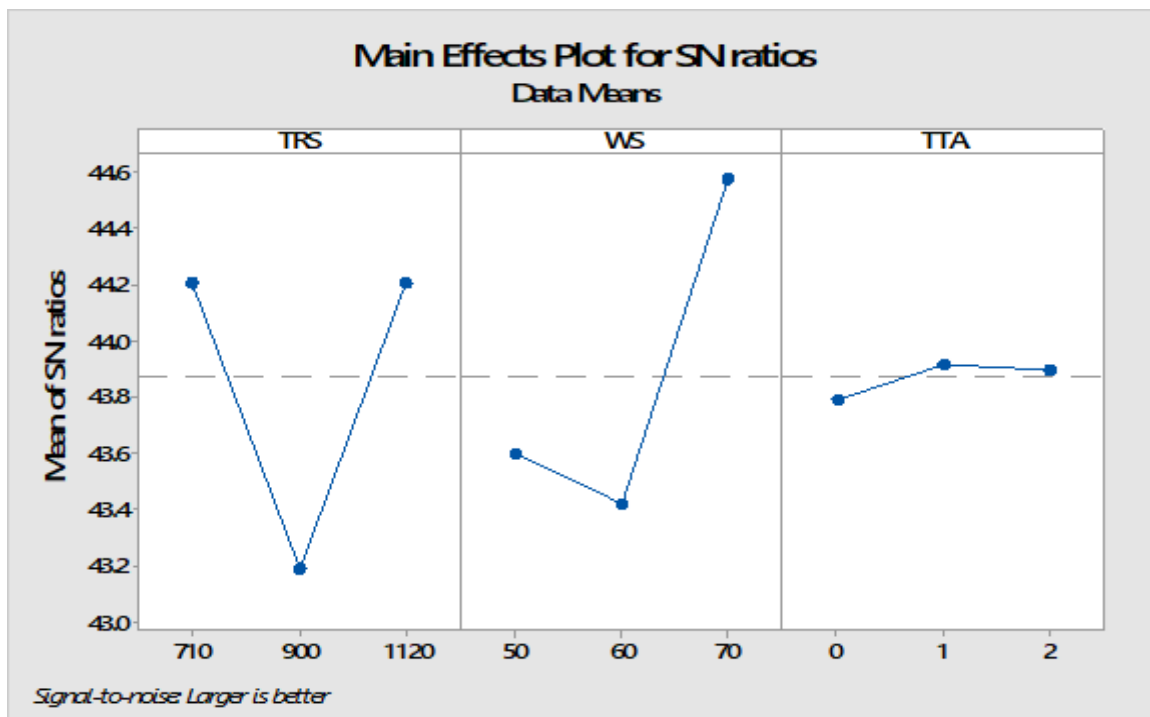


Figure 2

4.2 Yield strength

Yield strength is the amount of stress at which a material begins to deform plastically. . The value of the test specimen does not depend on the size of the work piece but it depends on factors like surface finish, the temperature of the test environment etc. Tensile testing of material was carried out at ASTM A370.

Thus, we need larger Yield strength to make the material withstand while stretched or pulled. Thus, we use Larger the better to calculate S/N ratio. Table 3 shows the ANOVA table for Yield strength.

Table 5 ANOVA table for YS

Source	Degree of freedom	Sum of squares	Mean of squares	F test	P test	Contribution(%)
N	2	625.0	312.5	0.55	0.601	15.59
W	2	808.0	404.0	0.76	0.509	20.16
D	2	2.680	1.340	0.3	0.749	9.18
Error	2	2572.1	586.88			
Total	8	4008.5				

From the table 5 we can clearly see that the combine contribution of tool tilt angle and tool rotation speed is much lesser than the welding speed. Welding speed has a major contribution of 20.16%. The optimum machining parameter can be found by response table which is shown in table 6.

Table 6 Response table for YS

Level	Tool rotation speed	Welding speed	Tool tilt angle
1	43.08	42.16	42.36
2	41.70	41.95	42.48
3	42.73	43.41	42.68
Delta	1.38	1.46	0.32
Rank	2	1	3

From the table 6 and figure 3 it can be concluded that tool rotational speed of 710 r.p.m, welding speed of 70 mm/min and tool tilt angle of 2 degree is the optimum machining condition to get a good yield strength

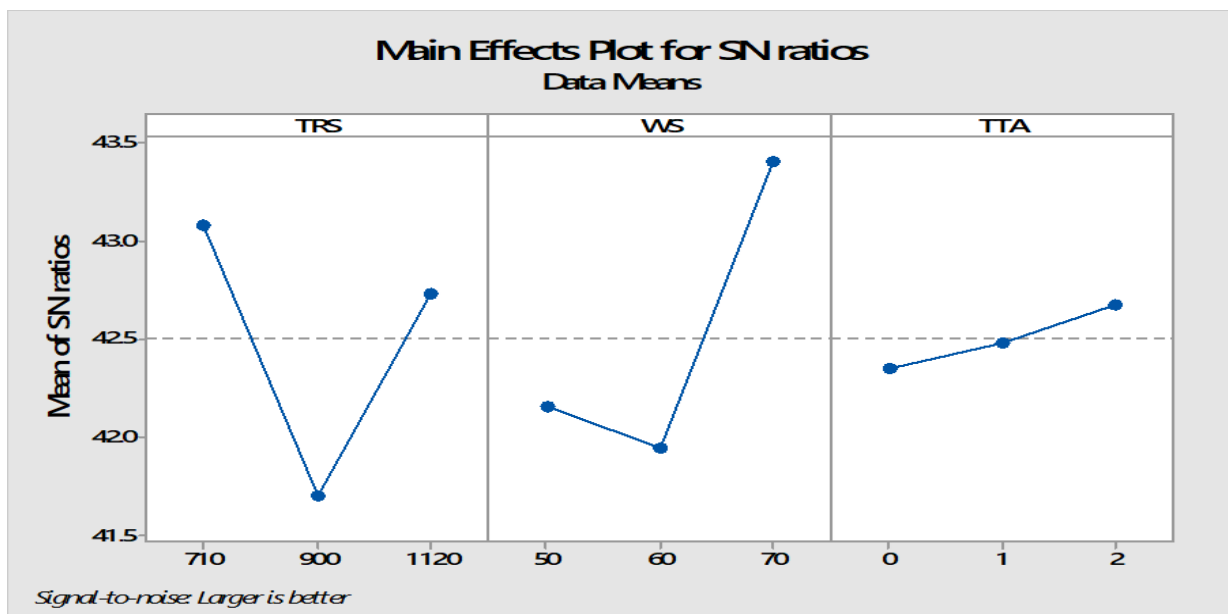


Figure 3



4.3 Percentage Of Elongation

Percent elongation is the percentage that a material stretches beyond its original length before it actually breaks. The value of the test specimen does not depend on the size of the work piece but it depends on factors like surface finish, the temperature of the test environment etc. Tensile testing of material was carried out at ASTM A370. Thus, we need larger Yield strength to make the material withstand while stretched or pulled. Thus, we use Larger the better to calculate S/N ratio. Table 3 shows the ANOVA table for Yield strength.

Table 7 ANOVA table for POE

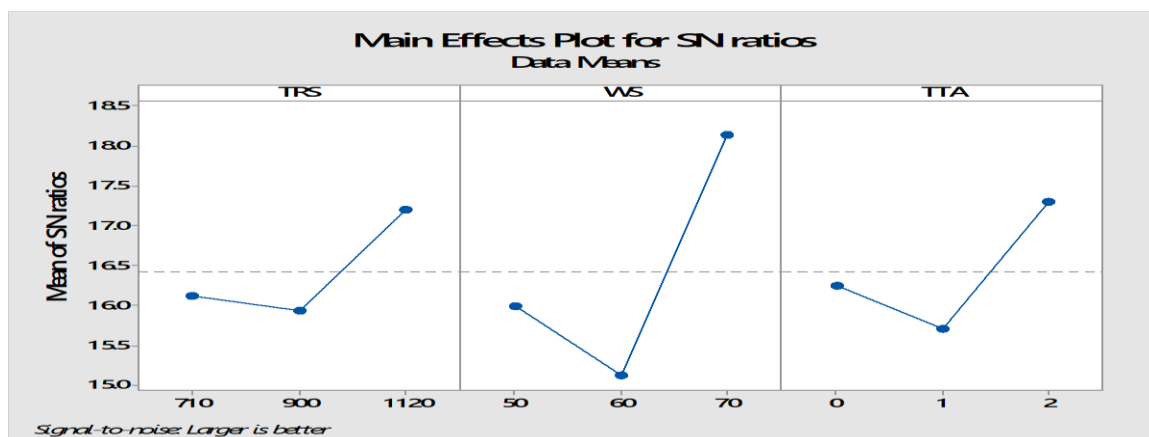
Source	Degree of freedom	Sum of squares	Mean of squares	F test	P test	Contribution(%)
N	2	2.680	1.340	0.30	0.749	9.18
W	2	8.803	4.402	1.3	0.341	30.15
D	2	1.321	0.6604	0.14	0.87	4.52
Error	2	16.392	4.154			
Total	8	29.196				

From the table 7 we can clearly see that the combine contribution of tool tilt angle and tool rotation speed is much lesser than the welding speed. Welding speed has a major contribution of 30.15%. The optimum machining parameter can be found by response table which is shown in table 8.

Table 8 Response table for POE

Level	Tool rotation speed	Welding speed	Tool tilt angle
1	16.11	15.99	16.24
2	15.92	15.11	15.70
3	17.20	18.13	17.29
Delta	1.28	3.01	1.59
Rank	3	1	2

From the table 8 and figure 4 it can be concluded that tool rotational speed of 1120 r.p.m, welding speed of 70 mm/min and tool tilt angle of 2 degree is the optimum machining condition to get a good percentage of elongation.



Figure

V. CONCLUSION

In this study, the Taguchi method was used to obtain optimal condition for Friction Stir Welding of AA5083-6061 aluminium composite. Experimental results were evaluated using ANOVA. The results can be drawn as follows:

- A maximum tensile strength of 180.571MPa was exhibited by the FSW joints fabricated with the optimized parameters of 1120 rpm rotational speed, 70mm/min welding speed, 0 degree tilt angle, shoulder diameter of 21mm, collet diameter of 24mm, shank diameter 18mm, pin dia 6mm, pin length 5.5mm, pin profile taper square and HSS material tool.
- Welding speed was the major factor affecting the tensile strength.
- Tool rotational speed of 1120 r.p.m., welding speed of 70 mm/min and Tilt angle of 0 degree is the optimum machining condition to get a good tensile strength.
- The optimum machining condition to get high tensile strength is tool rotation speed of 1120r.p.m, welding speed of 70 mm/min and tilt angle of 0 degree.
- Welding speed has negligible influence on Tensile strength.

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