Multi objective optimization of submerged friction stir welding process parameters for improved Mechanical strength of AA6061 weld bead by using Taguchi-L18 based gray relational analysis

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Abstract

Submerged Friction stir welding (SFSW) is a moderation tool in the manufacturing industry. SFSW is used to join the AA6061-T6 plates in the seawater environment to different processes of parameters are tool rotation speed, feed rate and tilt angle. The experiments are done by using Taguchi's L_{18} orthogonal array and to analyze the response characteristics are Tensile strength and Microhardness. To obtain a single optimum combination of parameters for these two types of responses, gray relational analysis has been utilized. Gray relational grade and a single optimum setting have been acquired for the SFSW of AA6061- T6. One of the most affecting and influencing processes of parameter is to find by applying ANOVA and it is tool rotational speed is the maximum percentage contribution in the entire process.

Keywords : *Submerged Friction stir welding(SFSW); Taguchi's Method; gray relational analysis(GRA); Ultimate Tensile strength (UTS); Microhardness(HV);*

Introduction

FSW is a moderate technique to develop by TWI Cambridge for joining of aluminum alloys. This process is widely used in so many industries such as aircraft, aerospace,automobile, naval. FSW joints with high strength, low weld defects, low distortion and low cost are the main advantages of this method. FSW is comprised of a non-consumable specially designed rotating tool is inserted into the edges of the two plates heating the workpiece by the friction between tool and workpiece the tool transverse along the line of joint the material flows from advancing side to retreating side the producing joint in a solid state (Figure 1). In the FSW joints have three affected microstructural zones those are the heat affected zone (HAZ), nugget zone (NZ) and thermo mechanical affected zone (TMAZ) [1].

AA6061 is heat treatable alloy having a high corrosion resistance, high toughness and good strength. The FSW joint mechanical properties mainly affected on the process of parameters are the tool rotation speed, the tool transverse feed and the tool pin geometry and tilt angle. Sakurada et al., were the initially used submerged friction stir welding for AA6061. The results observed that the possible enough friction heat generate for welding even in the samples are under the water. FRATINI et al founded FSW of aluminum alloy plates with a cooling of water by the rotating tool during the process. The strength of the weld joint was observed to be more than that of NFSW. Zhang et al. investigated that the underwater FSW increases the tensile strength of NFSW AA2219 joints at low welding speed and observed no conspicuous impact in the higher welding speeds. It depends on the water cooling rate Liu et al. (2011) found that the thermo MAZ was the failure zone in the friction stir welded joint and the tensile fracture was exactly occurred and in the hardness improvement in the joint is essential to improve the tensile strength of the joint. S. S. Sabari et.al, found that the UFSW joint having the higher tool traverse feed exhibited higher tensile properties. In these conditions we find various aspects i.e., the lower heat generation, high grain boundary strengthening and more volume fraction of particles and the low hardness distribution region. In the normal FSW process temperature is affected on the stir zone and the base material is not affected in the process. The stir zone properties are drastically changed into the base material. Instead of this process water cooling is used to yield better weld joint properties this process is termed as SFSW process.

Kasam et.al., Kumar et.al, are studied TM with GRA approach for optimization of FSW process parameters for different combinations and dissimilar aluminum alloys and found that the tool feed is the most affective parameter for gray relational grade. Rajakumar et.al., conducted to study the effects of tool geometry and FSW process parameters on tensile strength, microhardness of AA6061 FSW joints. They showed that tool rotational speed and tool shoulder diameter are the most influence factors on mechanical properties. The relationship between the FSW parameters and the tensile strength of the joint was established by using the tools such as Taguchi, Analysis of Variance (ANOVA) and RSM used to optimize the FSW parameters.

In spite of the fact that broad research has been performed to show SFSW process the revealed research work is relating the procedure parameters to weld attributes is more. Additionally, the absence of concentrate has been accounted for so far to associate the procedure parameters with tensile strength and microhardness in the SFSW procedure. Thus, in this work, an endeavor was made to create exact relationship to predict the instrument revolution speed, apparatus feed rate and toll tilt edge to the rigidity and microhardness of weld nugget of SFSW AA6061 weld joints utilizing measurable devices, for example, design of experiments taguchi technique L18 orthogonal array (OA), analysis of variance(ANOVA) and gray relational analysis(GRA).

Experimentation

The base material (BM) is used for the experiments a 6 mm thick 6061 aluminum alloy, the chemical compositions values and mechanical properties of BM and tool material are listed in Table 1.The plates were prepared into rectangular shaped plates with dimension of 230 mm long by 60 mm width and the edges are prepared in a straight manner. After cleaned by acetone, the samples were clamped in a straight manner tool travel line to the backing plate in a tank, and then the water at room temperature was poured into the tank to submerge the top surface of the work plates.

Table.1.Chemical composition of AA6061

Element present	Si	Fe	Cu	Mn	Mg	Zn	Tn	Cr	Al	Others
6061% Present	0.4-0.8	0-0.7	.15-.4	.0-.15	.8 -1.2	.0 -.25	0 to .15	.04-.35	Bala nce	.o5-.15

Butt weld joints were manufactured under sea water utilizing an FSW machine along the tool travel direction of the welding plate are at a various welding speeds and various rotation speeds. The H13 welding tool of an 18 mm/diameter shoulder and a cylindrical conical shaped pin with the length of 5.7 mm and the maximum diameter of 6 mm minimum diameter of pin is 3mm. During the FSW, a 1° and 2^0 tilt angles and an axial load of 4.6 KN were applied to the welding tool. By using taguchi orthogonal array L18 OA (2^1 & 3^2)is used, the process parameters are placed in **table 2**.

Table. 2. Process parameters:

Factor	**Type**	**Levels**	**Values**		
Tilt angle T (degrees)	Fixed	2	1	2	*
Rotational Speed N (rpm)	Fixed	3	1100	1200	1400
Tool Feed F (mm/min)	Fixed	3	22	45	60

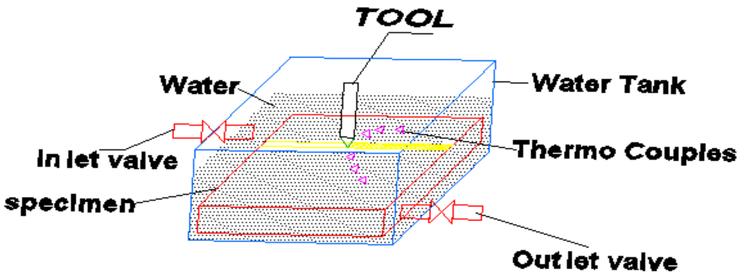

Fig. 1.shows the schematic view of the submerged FSW process.

After welding, the joined plates were prepared with the perpendicular to the welding direction for tensile test, metallographic analyses and Vickers hardness tests specimens are prepared by utilizing a water jet cutting machine.

Microhardness values measured from the center line of the thickness and polished cross sections with spacing from the weld center line of 1 mm between the adjacent indentations. The testing load was 3 N for 10 s.

The tensile test specimens are prepared as per the ASTM-E8 standard. The tensile test is conducted at a cross head speed of 1 mm/min at room temperature by utilizing a computer-controlled testing machine (Instron-8801). The tensile properties are evaluated using two specimens cut from the same joint. The prepared tensile specimens were subjected to tensile test and its ultimate tensile strength is evaluated. The experiments were conducted according to the designed L18 OA. The following **Table 3** will give the values of designed experimental layout.

Optimization steps using Taguchi based gray relation analysis:

In the gray relational analysis (GRA), experimental results (UTS, Microhardness) are first standardized in the range somewhere in the range of zero and one, which is additionally called the normalization. Next, the gray relational coefficient is determined from the standardized experimental data to express the connection between the ideal and experimental test information. At that point, the gray relational grade (GRG) evaluation by averaging the gray relational coefficient relating to each process response. The general assessment of the various procedure responses depends on the GRG. Accordingly, optimization of the confounded different process responses can be changed over into enhancement of a single GRG. At the end of the day, the GRG can be treated as the general assessment of experimental data for the multi response process. Optimization of SFSW process parameters is the level with the highest GRG. By using the below equations GRA is as follows:

Normalization of the data of UTS and microhardness are larger is better performance characteristics is evaluated by using Equation (1).

$$x_i^*(\mathrm{k}) = \frac{x_i^0(k) - \min x_i^0(k)}{max\ x_i^0(k) - \min x_i^0(k)} \qquad (1)$$

Where k = 1 to n, i = 1 to 9, n is the performance characteristic, and i is the trial number

The gray relation coefficient $\xi_i(k)$ can be calculated as follows:

$$\xi_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(\mathrm{k}) + \zeta\Delta_{max}} \qquad (2)$$

Note that higher is better and is achieved when $x_i^*(\mathrm{k}) = x_i^0(\mathrm{k})$, I.e., when X= reference. Here $x_0^*(\mathrm{k})$ denotes the reference sequence, $x_j^*(\mathrm{k})$ denotes the comparability sequence, $\zeta \in [0\ \text{-}1]$ is the distinguishing coefficient; 0.5 is widely accepted, $\Delta_{0i} = \left\| x_0^*(\mathrm{k}) - x_i^0(\mathrm{k}) \right\|$ is the difference in absolute value between $x_0^*(\mathrm{k})$ and $x_j^*(\mathrm{k})$, $\Delta_{min} = min_{\nabla j \in k}$, $min_{\nabla j \in k}\left\| x_0^*(\mathrm{k}) - x_i^0(\mathrm{k}) \right\|$ is the smallest value of Δ_{0i}, $\Delta_{max} = max_{\nabla j \in k}$, $max_{\nabla j \in k}\left\| x_0^*(\mathrm{k}) - x_i^0(\mathrm{k}) \right\|$ is the largest value of Δ_{0i}.

After calculating gray relational coefficients, the GRG is obtained as follows:

$$\frac{1}{n}\sum_{i=1}^{n} \xi_i(k) = \mathrm{Y}_i \qquad (3)$$

Normalized, Gray relational coefficient and GRG of experimental results UTS and HV are placed in the tabular form 3.

Table:3 GRA analysis

						Normalizing Step-1		Grey relational coefficient			
Sno	Tilt angleT	Rotation Speed N	Tool Feed F	UTS	HV	**UTS**	**HV**	**UTS**	**HV**	**GRG**	**Rank**
1	1	1100	22	163	96	0.368	0.376	0.442	0.445	0.443	15
2	1	1100	45	160	91	0.211	0.108	0.388	0.359	0.373	17
3	1	1100	60	156	89	0.000	0.000	0.333	0.333	0.333	18
4	1	1200	22	165	100	0.474	0.565	0.487	0.534	0.511	11
5	1	1200	45	162	98	0.316	0.457	0.422	0.479	0.451	14
6	1	1200	60	161	95	0.263	0.296	0.404	0.415	0.410	16
7	1	1400	22	174	105	0.947	0.860	0.905	0.782	0.843	2
8	1	1400	45	172	103	0.842	0.753	0.760	0.669	0.715	4
9	1	1400	60	169	99	0.684	0.538	0.613	0.520	0.566	8
10	2	1100	22	167	100	0.579	0.591	0.543	0.550	0.547	9
11	2	1100	45	166	98	0.526	0.465	0.514	0.483	0.498	12
12	2	1100	60	164	99	0.441	0.511	0.472	0.505	0.489	13
13	2	1200	22	170	103	0.711	0.753	0.633	0.669	0.651	5
14	2	1200	45	168	101	0.632	0.645	0.576	0.585	0.580	7
15	2	1200	60	166	101	0.500	0.618	0.500	0.567	0.534	10
16	**2**	**1400**	**22**	**175**	**108**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1**
17	2	1400	45	173	104	0.895	0.823	0.826	0.738	0.782	3
18	2	1400	60	171	100	0.789	0.591	0.704	0.550	0.627	6

Taguchi Method/Gray Relational Analysis:

By using GRG values apply taguchi analysis. In this analysis larger is better for both UTS and HV combined GRG. In the Taguchi method by using mean value of GRG is identified at the Level of factors are affected to the responses by determined using ranking. In this response of mean in the SFSW Process the main affecting parameter is tool rotation speed is having first rank and feed rate having the second affecting parameter and finally tool tilt angle is least affecting parameters. Those values are in the placed in the tabular form.

Table.4.Response Table for Means

Level	Tilt angle T	Tool Rotational Speed N	Feed F
1	0.5162	0.4473	**0.6659**
2	**0.6342**	0.5227	0.5666
3		**0.7555**	0.4931
Delta	0.1180	0.3082	0.1728
Rank	3	1	2

GRG Mean value= 0.575188

Optimum Levels of the factor is analyzed by using Analysis of variance (ANOVA) in Minitab17 software. The average GRG for each level of the factor is computed. The higher the GRG implies the better quality characteristics. Based on the higher GRG the optimal of the each controllable factor is determined. The average GRG and the optimal levels of the affective factors are listed in Table 8. The optimum levels of the process parameters based on the GRG is tilt angle is third affected parameter at the level 2 of 2^0 and Tool rotation speed is the main affected parameter at the level 3 of 1400 rpm and feed rate is the second priority parameter at 1^{st} level of 22 mm/min the order is writing in T2N3F1.Finally the UTS and microhardness are affected by the order of tool rotational speed, feed rate and tilt angle.

The prediction value is calculated by using GRG values =T2+N3+F1-2*average mean

=**0.905**

The ANOVA summary results of the GRG, as appeared in Table 5, indicates that tool tilt angle, tool rotation speed and feed rate significant SFSW process parameters, respectively, for influencing the different performance characteristics. This result concurs with the consequences of the response table for the GRG, as appeared in Table 5. Based on the past discussions, the optimal SFSW process for the best multiple performance characteristics is predicted to be the case of tool rotation speed at level 3 of 1400 rpm, tool tilt angle at level 2 of 2 degree and transverse speed at level 1 of 22 mm/min. The last step is to predict and check the optimal SFSW process parameter combinations for the best multiple performance characteristics. Yet standard SFSW processing parameters are not available in the literature because SFSW is a novel material joining technique. The process parameters are contributed in this order the tool rotation speed is maximum affecting process parameter of 61.63%, tool feed rate is 17.95%, Tilt angle is 12.47% and the error percentage in this experimental is 7.95. The predicted value of GRG is 0.905 at optimal process parameters and from the experimental results GRG is 1.00 the deviation is 0.095

Table.5. Analysis of Variance (ANOVA)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution %
Tilt angle T(degree)	1	0.06269	0.062695	18.84	0.001	12.47
Rotational Speed N(rpm)	2	0.30973	0.154863	46.53	0.000	61.63
Tool Feed F (mm/min)	2	0.09020	0.045102	13.55	0.001	17.95
Error	12	0.03994	0.003328			7.95
Total	17	0.50257				

Conclusion

By using the taguchi based Gray relational analysis to optimizing the SFSW process with the multiple objectives has been reported in this research paper. A gray relational analysis of the UTS and Microhardness objectives from the single objective is called the GRG. The optimal conditions of SFSW have been obtained for the weld joints of AA6061. The optimal SFSW process parameter combinations are tool rotation speed at 1400 rpm, feed rate at 22 mm/min and tilt angle at 2^0 for the best multiple objectives. The most affective SFSW process parameter is in the line of order is the higher tool rotation speed, lower tool feed rate and higher tool tilt angle.

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