Modelling and optimization of friction stir welding parameters of Mg-ZE42 alloy using grey relational analysis with entropy measurement

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Abstract. This research work focuses on ZE42 magnesium alloy processed by using four different friction stir welding (FSW) input parameters then modelled and optimized by grey relational analysis with entropy measurement are made. Input parameters are choose to evaluate a quality welding by axial force, tool rotational speed, welding speed and tool pin profile. Tensile strength (TS) and prediction of hardness strength (HS) responses are noted to optimize the welding characteristics. Welding experiments is planned and conducted by L9 orthogonal array design of experiment. Analysis of variance is used to decide the significant parameters over these parameters. Entropy measurement is added to optimize the quality welding characteristics on each parameter. Grey relational grade variance results predicts, tool pin profile is the most significant parameter whereas welding speed and axial force is less significant process parameters from grey relation grade. The grade results are validated by confirmation experiments.

Keywords. Friction stir welding, Magnesium alloy, Taguchi method, grey relation analysis, analysis of variance.

1. Introduction

ZE42 series of magnesium alloys grabs the interest because of its better choice of mechanical properties comparable to several unusual earth components that were encouraging in getting involved with commercial applications in transport, aerospace, automobile and other sectors, as detailed [1]. The microstructure evolution and thermal analysis of Mg alloy sheet particles and realized the alloy possess comparative tensile properties at several temperatures [2, 3]. FSW basic concept is very simple in which an unpreserved revolving apparatus, is implanted obsessed by the hitting limits of rods that are contains of pin and shoulder Fig. 1, designate combined and moved laterally the line of joint when the shoulder hints the material surface [4]. Some authors found that outcome of welding constraints for example pin profile, tool speed, FSW swiftness, and force are creating the joining value for most of the authors [5, 6]. With the purpose of learn the result of weld input conditions, some authors follow theconventional investigational practices, by fluctuating different constrains but making insignificant

parameters [7]. Above mentioned numerous performances to improve the weld limitations for creating the greatest value on the weld material for instance orthogonal array, Box Behnken design, grey relational analysis etc. Some of the authors (Ravishankar et al., Arunkumar et al. Periyaswamy et al., Prakashkumar et al., Kamalraj et al.,) practiced grey relational analysis on friction stir welding for optimizing studies to fusion of different materials. Ravishankar et.al applied Taguchi modelling and optimisation of friction stir welding on AA6061 Alloy [8]. Authors are experienced about device speediness is additional substantial method constraint than joining speed in FSW.
In multi objective optimization, it is necessary which factor is more important for deciding the performance of any process [9]. Kamal Jayaraj et al. Developed electro chemical rust performance of welding region of FSW welded different joints of AA6061 aluminium–AZ31B magnesium alloys. They discussed about diameter ratios are more important factor to estimate the quality of welding joints [10]. Prakash et al. Noticed best of FSW responses by Taguchi followed grade prediction and optimization of input values in FSW processed AM20 mg alloy. In this study, ANOVA is also used for finding the percentage contribution of FSW process parameter on one multiple objective. Taguchi method is used for evaluating the valuations; also find the grade with entropy rank calculation is followed for multi-objective optimization. Hardness prediction and Tensile strength are the suitable parameter to find the as the excellence welding solutions.

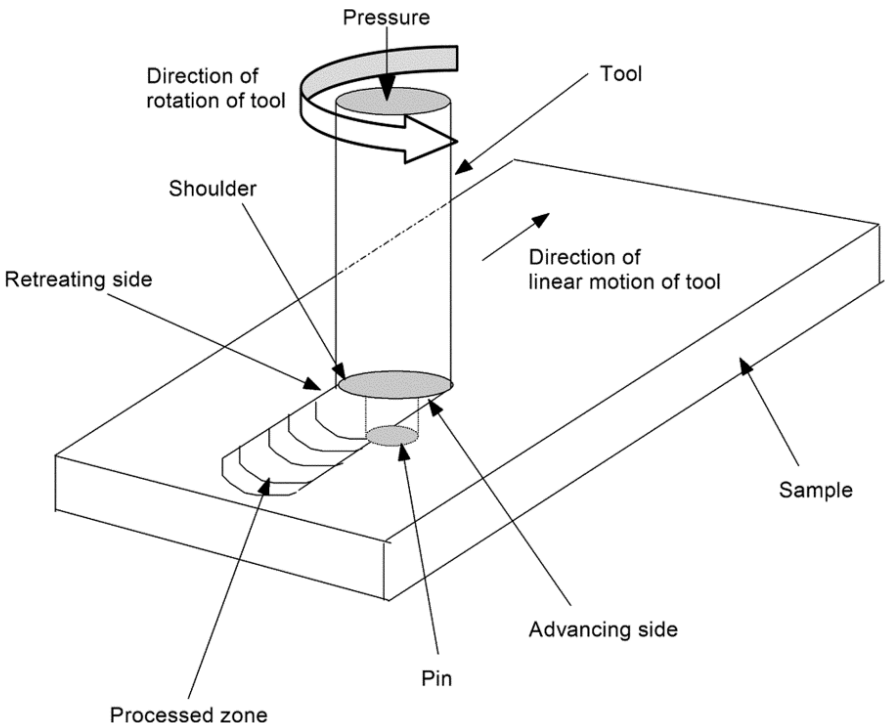

Figure 1. Friction Stir Welding Process

2. Experimentation based on Taguchi methodology

Conducting the experiments with this friction stir welding ZE-42 magnesium alloy 150 mm thick plate of was used as base metal. Butt joint configuration using vertical milling machine with special machine was used for welding process. Followed the survey of earlier narrative, important limits provide better manipulate on involuntary conditions is measured that are tool profile, tool turning speed, FS speed and axial force. The main parameters and their levels are summarized in Table 1. In this technique, selection of optimum level of processparameters is very complicated, in which one parameter is varied at a time and other parameters are kept constant. This optimization purposes this technique involves a large numberof experiments and more time consuming [11].

Table 1. FSW process parameters and variable levels

Parameters	symbol	Level 1	Level 2	Level 3	Units
Welding speed	N	900	1050	1500	RPM
Rotational speed	S	5	10	15	mm/min
Tool pin profile	P	-1	0	+1	-
Axial force	F	4	6	8	KN

To avoid these problems design of experiment based Taguchi method can be used for reducing the number of experiments. Taguchi has suggested various orthogonal arrays (OAs) for performing the experiments. The Taguchi design is selected for all input parameters on the basis of level of choice. In the current work, four input parameters and each having three levels. The total d_{offs} or the experiments must be lesser or equivalent to the sum level of choice particular OA by Taguchi method. Therefore, orthogonal L_9 array taking d_{of} was followed for evaluating the designs [11]. The coded value of L_9 array inputs to these responses is denoted in Table 2. ASTM E8 standard was used for prepared the tensile test specimens. Response parameter for tensile prediction was conceded out in 25kN, mechanical operated testing machine at experimental area atmosphere. The investigational outcome founded on L_9 OA is given in Table 2.

Table 2. Process parameters and Experimental result using L9 array design

Sl.No.	N	S	P	F	T	H
1	1050	80	-1	4	153.4	74.3
2	1500	60	0	8	180.6	83.6
3	1150	60	0	6	166.1	80.3
4	1050	40	1	8	164.3	79.7
5	1050	40	-1	2	164.2	81.1
6	950	60	0	6	142.9	70.4
7	1150	60	2	8	172.3	71.2
8	1150	40	0	4	158.2	76.5
9	1250	80	-1	6	145.8	66.4

3. Grey relation analysis

In GRA firstly the experimental data are normalized inzero to one range, and the process is called grey relation generation. The normalization is computed using the following equations [10]:

3.1. Generation of Grey relational value

GRA be able to structure into three ways accordingly Higher the better, Lower the better criterion. A linear statistic reviving out method to the MRR is the higher-the-better [6] and is shown as:

$$X_i^*\left(\mathrm{k}\right)=\frac{\mathrm{y}_i\left(\mathrm{k}\right)-\min y_i(\mathrm{k})}{\max y_i\left(\mathrm{k}\right)-\min y_i(\mathrm{k})} \quad (1)$$

Similarly the normalized data processing for SR is lower the better can be expressed as:

$$Y_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min\min y_i(k)} \quad (2)$$

The normalized values are shown in table 4. Here k= 1, 2,….n; i= 1, 2,….,m;

3.2. Grey relational coefficient

Equation 3 is given below is used to estimate grey relation coefficient in this study.

$$Z_i(k) = \frac{\Delta\min + \omega\Delta\max}{\Delta_{oi}(k) + \omega\Delta\max} \quad (3)$$

Where $\varepsilon_i(k)$ is the grey relation coefficient. Δ_{oi} is deviation among $y_o(k)$ and $y_i(k)$; $y_0(k)$ is the ideal sequence; Δmax is highest value of $\Delta_{oi}(k)$; Δmin is least value of $\Delta_{oi}(k)$.

3.3. Grey relational grade

Grades are resolute by finding standard values between of the gray relation constant associated with each observation as bestowed in equation (4).

$$\Gamma_i = \frac{1}{M}\sum_{=1}^{Q} i(k) \quad (4)$$

The gray relative grades represent stage of correlation between within the orientation and therefore the proportional cycle varies here. In this situation the value of each response is dissimilar. Where M is total amount of outputs and n expresses the number of existing values [11]. For solving this type of problem the grade values are calculated the rank of experiments calculated with entropy measurement.

$$\psi_i = \sum_{j=1}^{p} w_j \vartheta_{oi}(j) \quad (5)$$

Where i=1.....m, the weight for each quality characteristic can be calculated by using entropy method. The total sum of entropy is

$$E = \sum_{i=1}^{p} e_j \quad (6)$$

Table 3. Order of all quality features after Experimental data pre-processing

Exp. No	Comparability Sequences		Deviation Sequences	
	HS	UTS	HS	UTS
1	0.00000	0.00000	1.00000	1.00000
2	1.00000	0.976109	0.00000	0.76109
3	0.72332	0.00000	0.59727	0.68774
4	0.68379	0.843003	0.83959	0.95849
5	0.54347	0.887372	0.93856	0.51185
6	0.00000	0.511945	0.37884	0.95454
7	0.84782	1.00000	0.86956	0.00000
8	0.56917	0.733788	0.59451	0.54347
9	0.32411	0.389078	0.92832	0.95059

Table 4. Values of Grey relation coefficient, grey relation grade and rank

Exp. No	Grey Coefficient		Grey relational Grade	Rank
	HS	UTS		
1	0.687476	1.00000	0.84525	3
2	1.00000	0.960656	0.93856	1
3	0.643766	0.444613	0.59727	6
4	0.612591	0.441931	0.83959	4
5	0.615572	0.890578	0.7854	5
6	0.405449	0.333333	0.37884	9
7	0.766667	0.757106	0.86956	2
8	0.537155	0.676674	0.59451	7
9	0.425215	0.445967	0.72832	8

4. Result and discussion

The performance of friction stir welded joints is decided onthe basis of maximum value of tensile strength and hardness strength of welded joints. Tensile strength and hardness strength are selected higher is better type for normalization in GRA approach. The normalized values of TS and HS are given in Table 3. The grey relation coefficient of TS and HS was computed using equation (3). The weight value of TS and HS is initiate as .9761 and 0.8478, separately by means of equation (6), next weight of both responses has been used to compute the grey relationgrade by using equation (4). The grey relation coefficient and corresponding grey relation grade for each experiment are given in Table 4. Table 4 is evidently experiential it is found that second experiment gives significant routine for responses TS and HS between the experiments [12]. Effects of FSW input constraint on grade shown in Table 4. Since maximum average greyrelation grade optimum parameter level has been found as $N_2S_3P_1F_3$, i.e., tool rotational speed at 1050 RPM, welding aped at 60 mm/min and axial force at 6 kN.

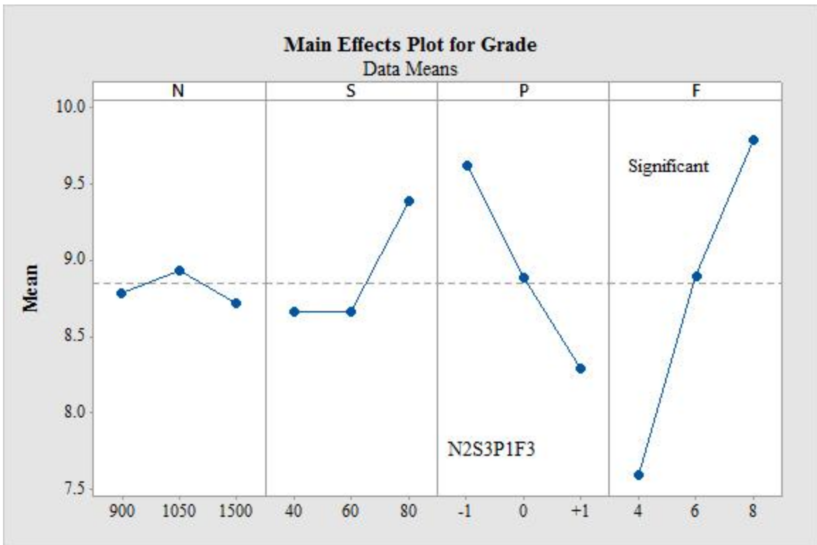

Figure 2. Main effect of grey relational grade

Figure 2 shows the significant result of grade in the analysis. The variation among the maximum and lowest ideals of the GRG of the FSW process parameters are as given below: axial force, rotational speed and FSW speed. By comparing this quality description of most effective parameter affecting is determined. Input process parameters give the level of consequence of over the multiple quality description when comparing the input conditions of FSW. Here, themaximum value is 9.7523 presents that the axial force shows the most significant result arranged the superiority conditions with the further input limitations.

Table 5. ANOVA for Grey relation grade

Source	DF[a]	AdjSS[b]	Adj MS[c]	F-value	Contribution
N	2	0.262	0.262	0.5	4%
S	2	6.3317	6.33166	12.09	13%
P	2	2.9692	2.96921	5.67	10%
F	2	8.94	8.94	17.07	68%
Error	2	6.2834	0.52361		5%
Total	8	36.0419			
Significant at 95% of confidence level					

Table 5 shows the result of ANOVA for grey relation grade, results are presents the axial force is the mainly considerable process parameter than tool rotational speed [13]. The percentage of contribution of each influencing process parameter is shown in Figure 3. Tool profile responses are largely contributed to the grey relation grade.

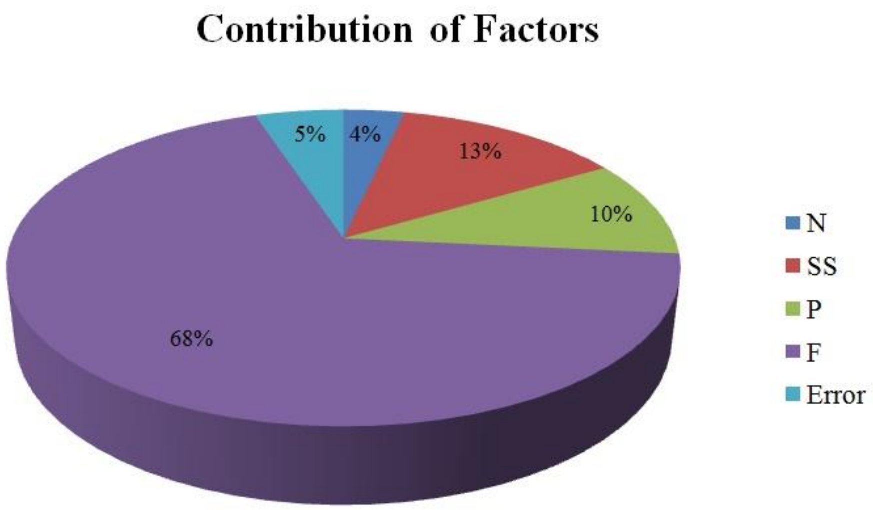

Figure 3. Contribution of influencing parameters

4.1. Confirmation test

After the selection of optimum FSW process parametersnext is to predict the quality characteristic at optimal levelof process parameters. The estimated grey relation grade at optimum process parameters calculated. The result of confirmation experiment hasbeen shown in Table 6. Tensile strength and hardness strength is increased from 180MPa to 187MPa, 83.6 to 85.9 MPa respectively.

Table 6. Results of confirmation experiment

Objective	**Process parameters**		
		Prediction	**Experiment**
Level	$N_3S_1P_2F_3$	$N_2S_3P_1F_3$	$N_2S_3P_1F_3$
Tensile Strength	180	-	187
Hardness Strength	83.6	-	85.9
GRG	0.7878	0.86131	0.8451

5. Conclusion

L9 orthogonal Taguchi method with grade analysis is used to predict the eminence welding of FS Welded ZE 42-Mg alloy in this study. From this study following conclusions are derived:

_ ANOVA results predicts, tool pin profile is the most significant $N_2S_2P_1F_3$ process parameter for although welding speed and axial force is less significant input parameters for grade.

_ The quality level of FSW input parameters are foundas $N_2S_2P_1F_3$, which means tool speed at 1050 RPM, FSW speed at 60 mm/min, and axial force at 6kN.

_ The application of Taguchi-grey relation analysis methodology has increased TS and HS by 12% and 08% correspondingly. For this reason, it can be said that the planned methodology has been used to work out the multi objective problem with quality prediction characteristics.

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