

Chapter 13

Multi-response Optimization of FSW Process Parameters of ZE42 Alloy Using RSM-Based Grey Relational Analysis



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Abstract This study presents the multi-objective optimization using grey relational analysis (GRA) of friction stir welding (FSW) parameters of ZE42 alloy utilizing of 1.2 mm diameter H13 wire. Input parameters for welding process perform a predominant part in calculating expected quality in weld. The research has been carried out in accordance with the response surface methodology (RSM). The input parameters preferred were the welding speed, axial force, tool pin profile, and tool speed. The responses for quality targets preferred are the ultimate tensile strength (UTS) and hardness strength. Grey relational analysis has been preferred in optimizing the input parameters instantaneously allowing for output variables in much variable. Determination of optimal parameters combination is stated as $A_3B_3C_3D_3$ when welding speed at 1150 rpm, tool speed at 60 m/min, cylindrical tool pin profile at zero, and axial force at 5 N. ANOVA method finds its total weldment quality over different level of input parameters.

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13.1 Introduction

ZE42 alloy known as identic nickel–iron-based super alloy possesses outstanding hardness with substantial conflict oxidation including carburization at elevated temperatures [1]. It has been chosen as the most unavoidable material in power plants of next generation. Exclusive mechanical property pools with high temperature resistance and also corrosion resistance with varieties the preferred alloy beneficial for numerous applications comprising continuous exposure to higher range of temperatures in atmospheres which supports corrosion [2]. FSW welding practices an electrode and is safeguarded using argon gases safeguards from atmospheric contaminants, the group of molten weld wire [3]. Weld quality is preferred from directly or indirectly over process parameters on the weldments mechanical and weld bead geometry. Weld joint quality has a crucial requirement on the process parameter of weld [4]. Author expressed those manufacturers controlling the input parameters control in obtaining a better welded joint with the desired weld quality [5]. Normally, skilled operators select inputs on trial and error method that consumes time corresponding to new welded metal in the idea of finding a welded joint along the essential specifications. Many authors have published that computational analysis and evolutionary algorithms have been extensively involved in developing numerical expressions for the input parameters in the idea of determining the quality welding input parameters which may provide desired weld quality [6]. Kaushik et al. [7] used Taguchi method in optimizing input parameter along with its wear behavior in achieving the parameter that is efficient at most with aluminum composite. Ghangas et al. [8] examined the effect of process parameter for AA7036 T6 alloy on hardness of armor alloy for FSW by central composite design approach. Ramanan and Edwin et al. [9] acquired mathematical model equations for wire cut EDM parameters of aluminum composites and determined optimum responses using grey relational parameters for automated manufacturing. Prabhu et al. [10] found the FSW optimum responses for dissimilar pipe joints containing Taguchi method with the determination that greater range of heat input ended up with tensile strength of lower values. Padmanabhan et al. [11] improved the tensile strength on AZ31B alloy using GRA approach. Hakan et al. [12] detailed the application of friction stir welding process in optimizing parametric combination in the idea of yielding promising tensile strength and weld beam. Neela Rajan et al. used the transesterified jatropa oil input parameters of getting optimum using GRA and concluded with inclusion of heating time in achieving optimum parameters [13]. Above-mentioned literatures conclude that, it is strong that only a few works were performed in optimization of ZE42 alloy using GRA. Another strong inference would be that GRA is involved in optimizing the friction stir welding input for achieving the anticipated quality response. This work presents optimization using GRA on the FSW weld parameters. Two responses are tensile strength and hardness. In the responses, the grey relational grade (GRG), the greatest significant factor has been found. ANOVA method has been applied in finding the influence of individual factors.

Table 13.1 Input process factors and their levels

Parameters	Symbol	Level 1	Level 2	Level 3	Level 4	Level 5	Units
Tool speed	<i>N</i>	950	1050	1150	1250	1350	RPM
Welding speed	<i>S</i>	20	40	60	80	100	m/min
Tool pin profile	<i>P</i>	-2	-1	0	+1	+2	-
Axial force	<i>F</i>	3	4	5	6	7	N

13.2 Experimental Procedure

ZE42 alloy plates of aspect $100 \times 50 \times 6$ mm were welded by FSW process weld mechanism. From literatures and trail run experiments the operating input parameters increase the quality of FSW are recognized as axial load, tool rotational speed (TRS), welding speed and tool pin profile used [14]. Between the four influence parameters identified, two parameters were ought to be altered in machine. Numerous trials are completed in selecting the process parameters with upper and lower values [6]. Response surface method has been chosen, and the experiments have been performed consequently [9]. The input welding parameter and levels are detailed in Table 13.1. TRS was offered in welding machine and performed variation as per the estimated axial load. To estimate axial load generated in FSW process, a dynamometer is connected on the surface of specimen where the specimen and spindle get connection. Accordingly fixture is designed to place above a probe and is connected with dynamometer to calculate axial load produced through FSW process. The altered vertical milling machine, parameters achieved [6] for FSW process are axial load, tool pin profile, tool rotational speed, and welding speed used. The hardness and tensile test were carried out according to ASME standard. The experimental results are discussed in the response and contour plots.

13.3 Effects of Experimental Design

Design of experiments (DOE) is applied to identify the process parameters that contribute the best response. This design will be useful to relate the responses with input parameters [4]. To analyze the effect of FSW welding process parameters *N*, *S*, *P*, and *F* the response plot and contour plots are presented in Figs. 13.1 and 13.2. Figure 13.1 represents surface plot of hardness that tends to increase with axial load of 5 kN with increase in TRS between 950 and 1350 rpm. Likewise thread cylindrical shape tool pin profile produces high UTS with TRS of above 1150 rpm and other tool pins fail at various TRS. Welding speed also produces maximum strength with high TRS. From this, it is evident that plates with similar joints produce high strength. Figure 13.2 shows contour plot of hardness and UTS which tends to increase as axial load increases from 950 to 1350 rpm. Likewise tool pin profile produces high UTS with TRS of above 1150 rpm. The quality of the welding is done using the tensile

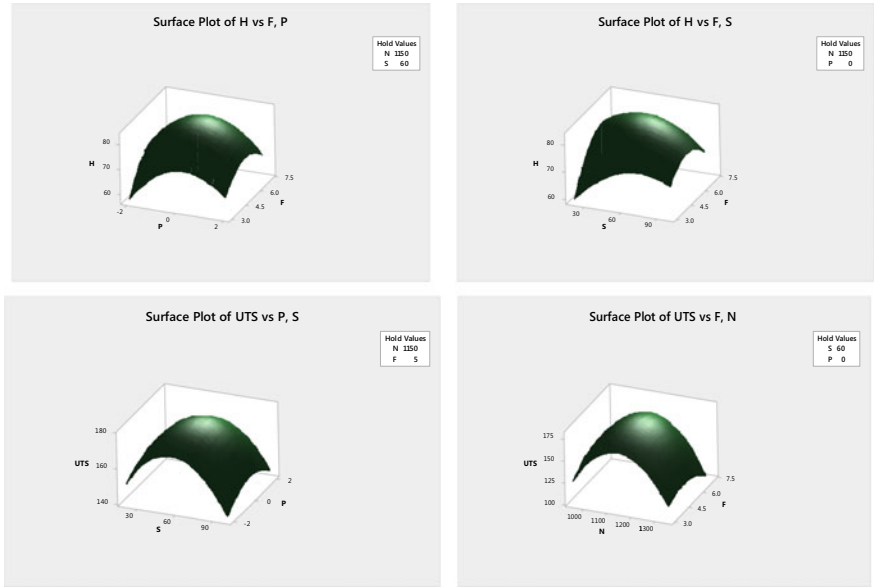


Fig. 13.1 Surface response plots for effect of process parameters with the responses

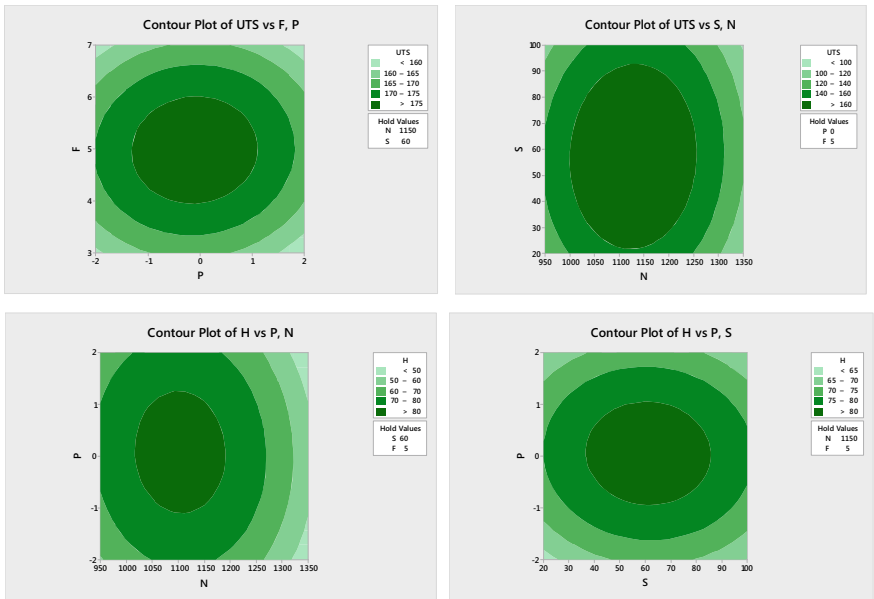


Fig. 13.2 Contour plots for effect of process parameters with the responses

testing, which is a simple method to find the reaction of material when applied to tension. The ultimate tensile strength of base material ZE42 alloy was 150 MPa. The entire welded region showed increased strength as compared to that of the other materials combination.

13.3.1 Grey Relational Analysis (GRA)

Initial step begins with the transformation of response data from the weld response values. Equation (13.1) has been used to find larger, better and subsequent analysis of S/N ratio values [6]. Through GRA, originally the input data are normalized by incorporating this normalized data, grey relational coefficient is assessed, and the GRC has been achieved by mean values related to nominated experiment data [9].

13.3.1.1 Grey Relational Generation

In GRA criterion, a linear data preprocessing method for the MRR is higher the better [5] and is conveyed as:

$$X_i^*(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (13.1)$$

Correspondingly the normalized data processing for SR is lower the better and can be articulated [5] as:

$$Y_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (13.2)$$

13.3.1.2 Grey Relational Coefficient

Determination of grey relation coefficient has been achieved by Eq. (13.3) as illustrated below [5]

$$\epsilon_i(k) = \frac{\Delta \min + \omega \Delta \max}{\Delta_{oi}(k) + \omega \Delta \max} \quad (13.3)$$

13.3.1.3 Grey Relation Grade

In the grey relation grades square measure estimated by considering mean of the GRC related with observation as presented in Eq. (13.4).

$$\Gamma_i = \frac{1}{M} \sum_1^Q i(k) \quad (13.4)$$

13.4 Results and Discussion

FSW on ZE42 alloy is carried out according to Box–Behnken design to investigate the effect of the FSW parameters, specifically, welding speed, tool speed, pin profile and axial force on the output responses, ultimate tensile strength, and hardness [14]. Box–Behnken design is to be widely used for optimization techniques because of the advantage of optimizing multifactor problems with optimum number of experimental runs. It is a statistical tool that allows the independent evaluation of the responses with maximum number of experiments. In determining the preferred set of FSW parameters for welding the ZE42 alloy better and effort has been given consistently.

13.4.1 Multiple Response Models Using GRA

By using GRA complicated optimization problem can be solved effectively. To have better contributing response parameters such as ultimate tensile strength, hardness of ZE42 alloy has been studied [14] using ANOVA and presented in Table 13.2.

Table 13.2 ANOVA table for FSW of ZE42 alloy

Source	DF	SeqSS	AdjSS	Adj MS	F	P	% contribution
N	2	0.014672	0.007724	0.003862	0.67	0.523	3.5243
S	2	0.054051	0.00507	0.002535	0.44	0.006	13.0936
S	2	0.041542	0.057846	0.028923	5.04	0.018	9.9788
F	2	0.284986	0.172981	0.08649	15.07	0.001	68.4558
Error	18	0.021201	0.010332	0.00574			
Total	26	0.416308					

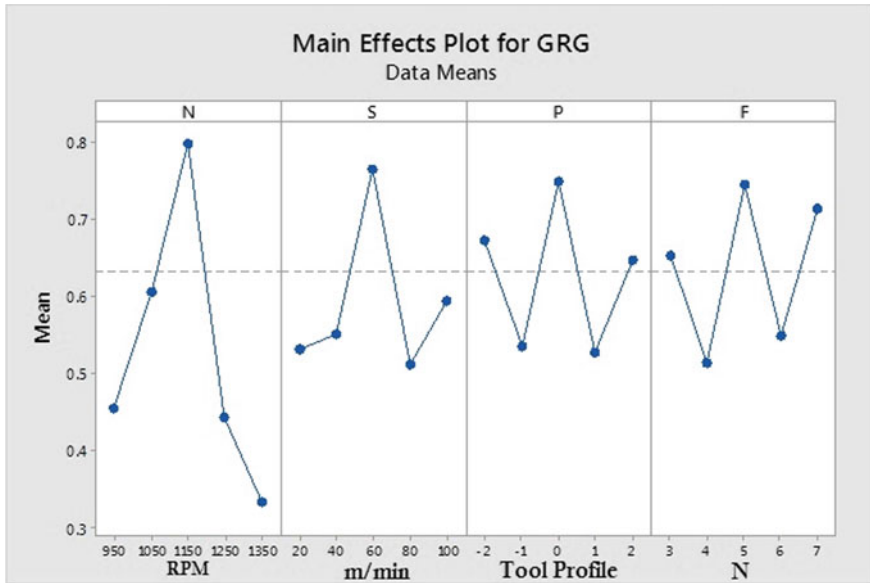


Fig. 13.3 Main effect plot of grey relation grade

13.4.2 Response Table for GRG Using S/N Ratio

The average GRC values for each set of the FSW parameters are prepared and were determined by average in all the levels of process parameters [10]. It illustrates optimal value of input parameters. Figure 13.3 details the foremost effect plot of grey relation grade. It reveals that $A_3B_3C_3D_3$ is optimal response which represents the welding speed of 1150 rpm, tool speed 60 m/min, pin profile of zero, and axial force of 5 N.

Welding speed was the foremost prompting factor, shadowed by the tool speed and axial force [13]. In Fig. 13.3, the graph shows the impact of rotational speed on responses which improves that with rise in speed from 950 to 1350 rpm grade decreases. In Fig. 13.3 second graph presents that the influence of welding speed increases over the strength of FSW process [11]. From third and fourth graph, it is states that with rise in welding speed and pin profile from gains after that reduced. On rise of axial force from 2 to 7 N, the strength level increased with it and then moderated at higher level [12].

13.4.3 Confirmation Check

While analyzing the FSW parameters, the important thing is to confirm the hardness and also the tensile strength by accompanying the validation experimentations is

Table 13.3 Validation of results against developed GRA model for FSW of ZE42 alloy

Response	Process parameters				Output parameters	
	A rotational speed	B welding speed	C pin profile	D axial force	Hardness (BHN)	UTS (MPa)
Initial	1250	40	Square	6	83.6	180.1
Optimal	1150	60	Cylinder	5	86.14	183.45
Experiment	1150	60	Cylinder	5	89.31	187.26

presented in Table 13.3. Here $A_4B_2C_4D_4$ is a quality parameter has been found during FSW process via the GRA. Consequently, the state $A_3B_3C_3D_3$ of the quality response level has been considered as consent check.

As perceived in Table 13.3, hardness goes up from 86.14 to 89.31 BHN and UTS value occurs from 183.45 to 187.26 MPa. As per the discussions of results which increased the strength of FSW process and confirming that the quality distinctiveness is highly considerable by enhancing via this confirmation test [15]. Significant effect in parameters and its percentage contribution gets changed compared to the parameter behavior with balanced response.

13.5 Conclusion

From results, response surface method with grey relational analysis plays a vital role in optimizing the FSW multiple responses such as hardness and UTS. An optimum set of test parameters of GRC for quality weld surfaces has been identified as the tool speed of 60 m/min, welding speed of 1050 rpm, cylindrical pin profile at zero, and axial force of 5 N. ANOVA results predicted that the axial force (68%) exerted a significant impact on FSW responses followed by welding speed (13%) and pin profile (9%). This study has shown that the measured responses of welded ZE42 alloy are greatly increased by grey-based response surface method for improvement in weld quality.

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