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Modeling of pulsed TIG welding parameters and optimization of the mechanical properties using statistical approaches

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Abstract

Using regression analysis to find optimum welding parameters. The response considered is Notch tensile strength (NTS). To develop the mathematical models, various linear and curvilinear regression functions have been fitted to the experimental data. The best model is chosen and Simulated Annealing (SA) Algorithm is then used to optimally determine input parameters levels in order to obtain any desired output, simultaneously. Finally, Taguchi method is applied to find the optimum parameters settings and compare the answers to the other method.

Keywords: TIG – Regression - Optimization - Simulated Annealing (SA) – Taguchi.

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Abstract

In this paper, an attempt is made to compare the feasiblity and effectiveness of Taguchi method and Simulated Annealing (SA) Algorithm by means of regression analysis to find optimum welding parameters of the pulsed TIG welding process. The response considered is Notch tensile strength (NTS). To develop the mathematical models, various linear and curvilinear regression functions have been fitted to the experimental data. The best model is selected and Simulated Annealing (SA) Algorithm is then used to optimally determine input parameters levels in order to obtain any desired output. Finally, Taguchi method is applied to find the optimum parameters settings. The results show that Both “the Taguchi method” and “regression + SA” found the optimum solution in a reasonable time; therefore both of these methods are able to find the optimum solution in such problems.

Keywords: TIG – Regression - Optimization - Simulated Annealing (SA) - Taguchi

1. Introduction

Tungsten inert gas (TIG) welding is an arc welding process that produces coalescence of metals by heating them with an arc between a non-consumable electrode and the base metal [1]. Difficulties have been reported in obtaining satisfactory properties in TIG welded condition particularly strength and toughness due to low dilution of the base metal into the weld [2]. Numerous research works exist on the modeling and optimization of process parameters in welding [3, 4]. Comprehensive surveys in this field can be found in literature [5]. Nevertheless, most of the proposed models are complicated and highly nonlinear. Some of these papers uses simulated annealing and some the Taguchi method and the effectiveness of these to optimization methods are not compared.

In the present work, an attempt has been made to carry out linear as well as curvilinear regression analyses on the data collected by Kumar and Sundarrajan [6] using an L_8 (2^7) orthogonal array. The text is organized as follows: Input-output variables of the process have been identified and their feasible ranges have been set. Both linear as well as curvilinear regression analyses carried out in the present work and the results are stated and discussed. SA algorithm is used to optimize the TIG process. Taguchi method is finally applied to find the optimum inputs and the results of the two methods are discussed.

2. problem statement

In order to achieve optimum welding performance, it is important to properly set the welding parameters. The selected input process parameters in this study and their levels of the TIG process are shown in Table 1 and the considered response is Notch tensile strength (NTS).

Table 1. Input factors and their levels of the process

Parameter	Units	Notation	Factors levels	
			Lower level	Higher level
Peak current	Amps	A	*180*	*200*
Base current	Amps	B	*60*	*72*
Welding speed	mm/min	C	*120*	*150*
Pulse frequency	Hz	D	*2*	*6*

The aim of the present investigation is to establish relations between the process parameters (inputs) and responses (outputs) for TIG welding, using regression analysis, where each response would have a single regression equation relating it to the process parameters for the whole domain of the investigation. The basic aim of the study is to compare the performance of the different regression approaches in predicting the weld bead geometry from the process parameters and finding the optimum input parameters using SA algorithm with the Taguchi method.

3. The solution procedure

3.1. SA algorithm

For real and large size optimization problems, the traditional optimization methods are often inefficient and time consuming. With the advent of computer technology and computational capabilities in the last few decades, the applications of heuristic algorithms are widespread. These techniques are usually based on the physical or natural phenomena. In 1953, Metropolis proposed a procedure used to simulate the cooling of a solid for reaching a new energy state. The annealing process, used in metal working, involves heating the metal to a high temperature and then letting it gradually cools down to reach a minimum stable energy state. If the metal is cooled too fast, it won't reach the minimum energy state. Later Kirkpatrick and his colleagues [7] used this concept to develop a search algorithm called Simulated Annealing (SA). Among different heuristic algorithms, SA is one of the most powerful optimization methods that simulates the cooling process of a molten metal. The general stages of the SA algorithm are as follows:

1. BEGIN: Initialize the temperature parameter T 0 and the cooling schedule; r (0 < r < 1) and the termination criterion (e.g. number of iterations k = 1… K). Generate and evaluate an initial candidate solution (perhaps at random); call this the current solution, c.

2. Generate a new neighbouring solution, m, and evaluate this new solution.

3. Accept this new solution as the current solution if:

3-a) The objective value of new solution, f (m), is better than of the current solution, f (c).

3-b) The value of acceptance probability function given by (exp (f (m) – f (c)) / T k) is greater than a uniformly generated random number "rand"; where 0 < rand < 1.

4. Check the termination criterion and update the temperature parameter (i.e., T k = r * T k-1) and return to Step 2.

The main advantages of SA are its flexibility, its fewer tuning parameters, and its ability to escape local optima and to approach global optimality.

3.2. Taguchi method

Taguchi's philosophy is an efficient tool for the design of high quality manufacturing system. Dr. Genichi Taguchi, a Japanese quality management consultant, has developed a method based on orthogonal array experiments, which provide much reduced variance for the experiment with an optimum setting of process control parameters. Thus, the Taguchi Method achieves the integration of design of experiments (DOE) with the parametric optimization of the process, yielding the desired results. The orthogonal array (OA) provides a set of well balanced (minimum experimental runs) experiments and Taguchi's signal-to-noise ratios (S/N), which are logarithmic functions of desired output, serving as objective functions for optimization. This technique helps in data analysis and prediction of optimum results. In order to evaluate optimal parameter settings, the Taguchi Method uses a statistical measure of performance called signal-to-noise ratio. The S/ N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The standard S/ N ratios generally used are as follows:
Nominal is best (NB), lower the better (LB) and higher the better (HB). The optimal setting is the parameter combination which has the highest S/ N ratio.

4. Modeling

To develop the mathematical models, various linear and curvilinear regression functions have been fitted to the experimental data. The best model is then selected based on two criteria, namely; correlation coefficient and Analysis of Variance

(ANOVA) results, with 95% confidence level. The calculated coefficient of determination R^2, P-value and F-value for regression functions are shown in Table 2.

Table 2. The calculated R^2, P-value and F-value for regression functions

objective function	R^2	P-value	F-value
First order	*82.1*	*0.000*	*12.63*
Second order	*90.2*	*0.002*	*10.50*
Third order*	*90.2*	*0.002*	*10.50*
logarithmic	*82.1*	*0.000*	*12.59*

Based on the Table 2, second order polynomial equations will be used for optimization. Note that all third order parts of the third order functions were highly correlated with other variables that they have been removed from the equations. Therefore, characteristics of second and third order equations are the same. But first insignificant factors should be removed from equations using step backward elimination with 95 percent confidence level. Therefore, the modified regression is as follows:

$$TS = 189 + 0.167\ C - 21.6\ D - 0.00330\ AB + 0.122\ AD \quad (1)$$

5. Optimization

SA Algorithm is used to optimally determine input parameters levels in order to obtain any desired output. For high quality joint in TIG welding Notch tensile strength (NTS) should be at its highest possible value. The algorithm along with its objective function has been coded in Matlab software. SA parameters are as follows: initial temperature: 1000, cooling rate: 0.99, termination criterion: 1000 iterations. The convergence curve of the SA is shown in Figure 2.

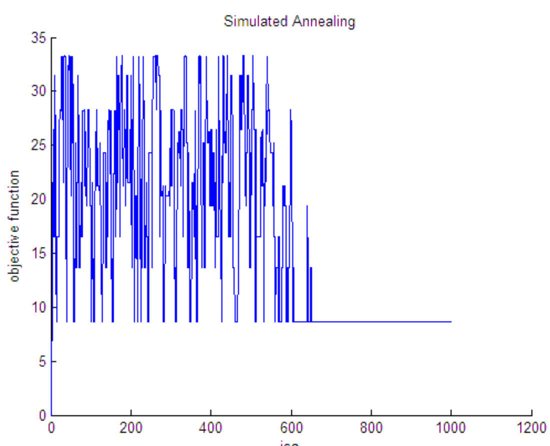

Figure 2: The convergence curve of the SA algorithm

The best input parameters to gain optimum results are as follows: A: 200, B: 60, C: 150 and D: 6. Since in all runs, which were started from random point, lead to one specific above mentioned answer, the answer is the global answer of the process.

6. Taguchi method

The L8 (2^7) OA Taguchi and the calculated S/N ratios are shown in Table 3.

Table 3. The L8 (2^7) OA Taguchi and the calculated S/N ratios

A	B	C	D	NTS (Trial 1)	NTS (Trial 2)	S/N ratios
1	*1*	*1*	*1*	*174*	*169*	*44.6825*
1	*1*	*2*	*2*	*185*	*180*	*45.2228*
1	*2*	*1*	*2*	*166*	*169*	*44.4793*
1	*2*	*2*	*1*	*173*	*170*	*44.6843*
2	*1*	*1*	*2*	*185*	*190*	*45.4577*
2	*1*	*2*	*1*	*180*	*180*	*45.1055*
2	*2*	*1*	*1*	*173*	*165*	*44.5504*
2	*2*	*2*	*2*	*183*	*180*	*45.1766*

Based on the graphical representation of the S/N ratios, in order to get the maximum NTS, lower level of B and higher level of A, C and D (A2B1C2D2) should be used as shown in Figure 3.

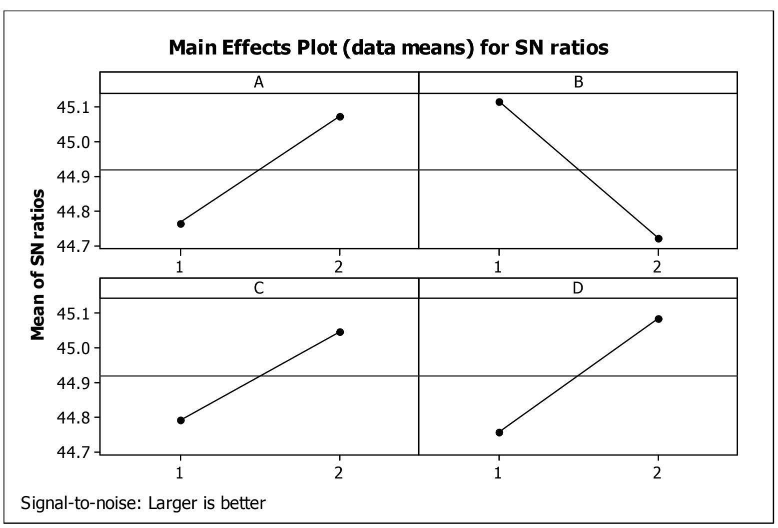

Figure 3. Main effects plot for S/N ratios

The ANOVA results show that B is the most effective parameter on NTS while C has the lowest effect on it.

Table 4 - Analysis of Variance for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	*1*	*0.18647*	*0.18647*	*0.18647*	*6.94*	*0.078*
B	*1*	*0.31121*	*0.31121*	*0.31121*	*11.58*	*0.042*
C	*1*	*0.12987*	*0.12987*	*0.12987*	*4.83*	*0.115*
D	*1*	*0.21574*	*0.21574*	*0.21574*	*8.03*	*0.066*
Residual Error	*3*	*0.0806*	*0.0806*	*0.02687*		
Total	*7*	*0.92388*				

Both “the Taguchi method” and “regression + SA” found the optimum solution in a reasonable time; therefore both of these methods are able to find such kind of problems.

7. Conclusions

The main trust of this research was to establish the mathematical relationships between input and output parameters and to explore the possibility of using SA algorithm in predicting input parameters values in TIG welding and comparing it to the Taguchi method. Along this line, using DOE approach and regression analysis, different mathematical models were developed to establish the relationships between welding input parameters and weld bead geometry. The ANOVA results denote that the curvilinear models are the best representative for the actual process. In this research, these models were put to use as a part of prediction procedure for determining process parameters for any desired outputs. To achieve this, a SA technique was developed to maximize the NTS. The same optimum combination (A2B1C2D2) is observed in notch tensile strength (NTS) using both “the Taguchi method” and “regression + SA”.

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