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Multi Objective Optimization of Robotic GMAW Process Parameters using Genetic Algorithm

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Abstract

In the present paper, Taguchi techniques has been applied for modeling robotic gas metal arc welding process parameters on IS 2062 E250 BR with output response as weldment mechanical properties in terms of Arc voltage, Arc current, Travel speed and Stick out as input processing parameters. The second order mathematical models in terms of process parameters were developed for output response using regression analysis on the basis of experimental results. The adequacy of the developed models on output responses has been validated with analysis of variances (ANOVA). The output responses are conflict in nature. Hence, the problem is formulated as a multi-objective optimization problem. The formulated problem is solved for optimization using an efficient evolutionary algorithm such as genetic algorithm and obtained the Pareto frontier solution. Confirmation experiments were conducted for validation of the results.

Keywords: Bead Geometry, Multi Objective Optimization, GA

Introduction

Welding is a complex metal joining processes with lot of interactive parameters, which depends upon the welding type and product requirements. Bead geometry is one of the performance indexes to meet the technical standards and customer satisfaction. The weld bead quality produced in the metal joining processes is influenced by various parameters given as shown in figure 1.

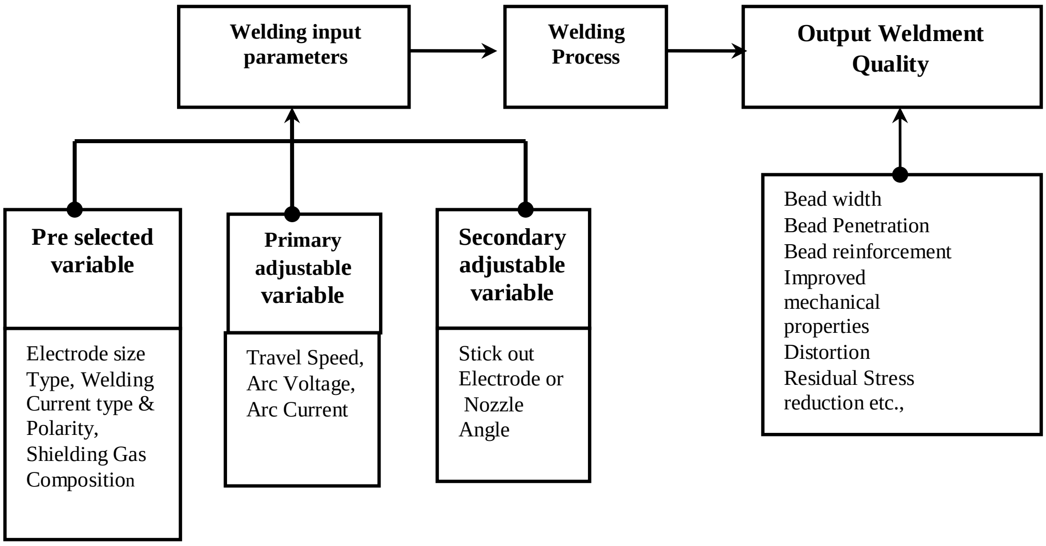

Figure 1: Welding Process

Selection of proper process parameters in welding for defect free product is so critical that it may affect the weld quality of the product. In past decades, even in automatic welding such as robotic welding, adopted welding, etc., selecting the welding conditions strongly depended upon an expert's judgment (programmer's control). It was very difficult for beginners or unskilled workers to determine the proper welding conditions to satisfy all required qualities such as the bead geometry and the material mechanical property. The selection of welding parameters, if it is done on trial and error method not only consumes more time but also leads to an inefficient process. At this junction, practical optimization strategy and reliable mathematical models are required for selecting the proper welding conditions.

Benyounis et al (2005) have applied Response Surface Methodology (RSM) to investigate and optimize the effect of laser welding parameters based on responses in CO_2 laser butt-welding of medium carbon steel plates of 5 mm thick. Gunaraj and Murugan (2000) have investigated the effect of Submerged Arc Welding (SAW) parameters on Heat Affected Zone (HAZ) characteristics and developed mathematical model using RSM techniques. Kim et al (2003a, 2003b and 2003c) have studied the interrelationship between robotic CO_2 arc welding parameters and bead penetration using linear and non linear multiple regression equations. The effect of measurement errors on uncertainty has been determined by employing sensitivity analysis using non linear equation in robotic Gas Metal Arc Welding (GMAW) process. The results show that all process parameters influence the responses and the models developed are able to predict the responses with 0–25% error. Mustafa N B and Khajavi (2006) have optimized welding parameters for bead penetration of Flux Core Arc Welding (FCAW) employing central composite rotatable design and response surface techniques. The effect of process parameters on penetration for Erdemir 6842 steel having 2.5 mm thickness welded by robotic GMAW were investigated by Erdal Karadeniz et al (2007). The effect of laser welding parameters on bead geometry of 2.5 mm thick AISI304 stainless steel has been investigated by Manonmani et al

(2007). Rajamanickam and Balusamy (2008) has carried out another work applying regression technique to establish the relationship between performance characteristics and its influencing factors for Friction Stir Welding (FSW) of 2014 type aluminum alloy. Sudhakaran R et al (2011) have studied the effect of welding process parameters on weld bead geometry and optimized the process parameters to maximize depth to width ratio for stainless steel gas tungsten arc welded plates using genetic algorithm. Katheresan et al (2014) have simulated FCAW using artificial neural network and optimized the same process using particle swarm algorithm.

Many researchers have been realized the difficulties accompanied with theoretical estimation of input – output relationships of welding process, they have been tried to get those response through statistical analysis of the experimental data viz., mathematical model. Those models include multiple linear as well as non linear regression, taguchi techniques, response surface methodology, evolutionary algorithms such as GA, PSO, SA, Tabu search etc., and others. Several efforts were made by various researchers to design a suitable model for welding process such as, using parameter optimization, analytical and numerical approaches etc. Furthermore, intelligent approaches were also adopted by many researchers to optimize the welding process conditions. They employed optimization techniques to optimize the weld bead geometry or mechanical property giving much emphasis on submerged arc welding, friction stir welding or other advanced welding such as electron beam welding, laser welding, etc. They concentrated on bead geometry or mechanical property produced in robotic GMAW. Therefore this paper focuses mainly on multi objective optimization of welding parameters such as arc current, arc voltage, stick out and travelling speed so as to achieve perfection in bead geometry (bead width, bead reinforcement and bead penetration) using of robotic GMAW at a reasonable cost.

Methodology

Using Taguchi's design of experiments, a plan for conducting experiments has been chosen based on the importance of input variables, which affects final quality of output (Philips Ross, 2005). The experimental data is used to develop mathematical models for design of first and second order models using regression methods. Analysis of variance (ANOVA) is employed to verify the validity of the model.

When dealt with real world problem such as welding, it has more than one parameter to control. Generally, these multi input parameters are conflicts to each. So finding solution using single objective optimization is meaningless. This paper dealt with the formulation of this multi objective optimization problem as the determination of the optimal welding conditions involves conflict between the maximizing bead penetration and minimization of bead width and height. For empirical equations are formulated through multiple regression techniques. The Classical optimization methods such as Weighted sum methods, goal programming, min-max methods etc, are not sufficient for handling the multi objective optimization problems as they cannot find the multiple solutions in the single run and hence, requiring them to apply many times to obtain the desired pareto optimal solutions. The application of evolutionary algorithm can easily find multiple solutions in a single run itself (Deb, 2001).

Many engineering optimizations problems, many researchers employed GA based multi – objective optimization methods to find the Pareto optimal solutions, at various situations [Srinivas and Deb, 1994]. GA based multi – objective optimization techniques prove its effectiveness with well distributed and well converged sets of near Pareto optimal solutions. Hence, in this paper, an efficient evolutionary algorithm, Genetic algorithm, is used for multi – objective optimization of robotic gas metal arc welding process to obtain the optimal process parameters. The aim of this research work is to study and optimize the parameters to obtain required quality of the weld bead by applying genetic algorithm for multi objective – optimization using MATLAB Toolbox.

Experimental Details

IS 2062 E250 BR is selected as a base material to determine the effect of welding process parameters such as Arc current, arc voltage, stick out and travel speed. The selected welding conditions are given in table 1. Four factors, three levels, L27 orthogonal array used to design the experiments.

Table 1: Experimental Details

Base material	IS 2062 E250 BR
Dimension	150× 100 × 10
Electrode	Copper coated mild steel wire (MIG welding wire) with diameter of 0.8 mm
Chemical Composition of Base metal	C – 0.15, Mn – 0.77, Si – 0.188, S – 0.022, P – 0.029, Al – 0.027
Mechanical properties of Base metal	Yield strength – 341 Mpa, tensile Strength – 499 Mpa , % Elongation – 26
Chemical Composition of Electrode	C – 0.06 to 0.15, Mn – 1.4 to 1.85, Si – 0.8 to 1.15, S – 0.035, P – 0.025 and Cu – 0.5

Modeling Using Taguchi's Techniques and Regression Analysis

In this paper, the regression analysis was adopted for process modeling in order to predict the bead geometry of welded component using robotic GMA welding. The general format for multiple regression equation is given in equation (1)

$$\hat{Y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 \quad (1)$$

X_1, X_2, X_3 and X_4 are input variables that represent arc current, stick out, arc voltage and travel speed respectively. The output response y is the value of the estimated bead geometry viz., bead width, bead penetration and bead reinforcement. β_0 is the y-axis intercept, and $\beta_1 \sim \beta_4$ correspond to the coefficient of each input variable. To find the coefficient of input variable, the method of least square is employed and the equation is given as follows

BW = 13.4954 + 0.07148 Arc current + 0.25958 Stick out +0.00649 Arc voltage – 48.9008 Travel speed (2)

BH = – 0.608578 + 0.01487 Arc current + 0.13548 Stick out – 0.00024044 Arc voltage – 8.84251169 Travel speed (3)

BP = 14.06574 + 0.003195 Arc current – 0. 25824 Stick out – 0.041272006 Arc voltage – 8. 4275321 Travel speed (4)

Table 2: Regression Statistics

	Bead Width (BW)	**Bead Height (BH)**	**Bead Penetration (BP)**
Multiple R	0.980381818	0.882848955	0.93193028
R Square	**0.961148509**	**0.779422278**	**0.868494047**
Adjusted R Square	0.954084602	0.739317237	0.844583874
Standard Error	0.688517204	0.370026574	0.263838428
Observations	27	27	27

Table 3: ANOVA

		df	***SS***	***MS***	***F***	***Significance F***
Bead Width	Regression	4	258.009136	64.502284	136.064	3.523E-15
	Residual	22	10.4292307	0.47405594		
	Total	26	268.4383667			
Bead Height	Regression	4	10.47517575	2.618793937	19.0618	6.7601E-07
	Residual	22	3.022451801	0.137384173		
	Total	26	13.49762755			
Bead Penetration	Regression	4	10.11393631	2.528484078	36.3232	2.1481E-09
	Residual	22	1.531435751	0.069610716		
	Total	26	11.64537206			

Table 4: Response Table for Means

Level	**Arc current (Amps)**	**Stick out (mm)**	**Arc Voltage (Volts)**	**Travelling speed (mm/min)**
1	11.01	11.63	11.13	11.59
2	11.07	11.07	11.15	11.16
3	11.20	10.59	11.01	10.54
Delta	0.19	1.03	0.14	1.05
Rank	3	2	4	1

Using statistical software Minitab, ANOVA calculations were computed. Usually, the change of the welding process parameter has a significant effect on the quality characteristic when the F value is large. The results of bead geometry are tabulated in Table 2. As per this technique it was found that calculated F ratios were larger than the tabulated values at 95% confidence level; hence the model is considered to be adequate. One more criterion that is commonly used to illustrate the adequacy of a fitted regression model is the coefficient of determination (R^2) and adjusted R^2. For the models developed the calculated R^2 and adjusted R^2 values are provided in Table 3. These values indicate that the regression model is quite adequate. It indicates that the considered process parameters are highly significant factors, which affects the bead geometry of robotic GMAW joints.

The S/N ratio of the bead geometry is listed in Table 4. In this case, it is smaller the better, it is clearly known that the parameter travelling speed is the most influential parameter than arc current and arc voltage. From that it is evident that travelling speed plays a major role in the formation of bead geometry and its main effects plot and its interaction effects plots are shown in Figure 2a and Figure 2b. The residual plots for S/N ratio are shown in Figure 3.

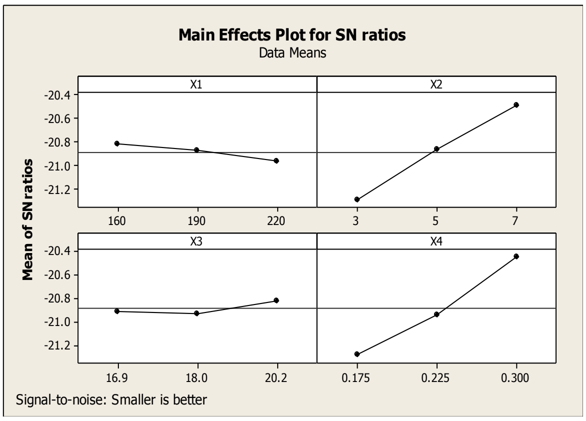

Figure 2a: Main effects Plot for S/N ratio

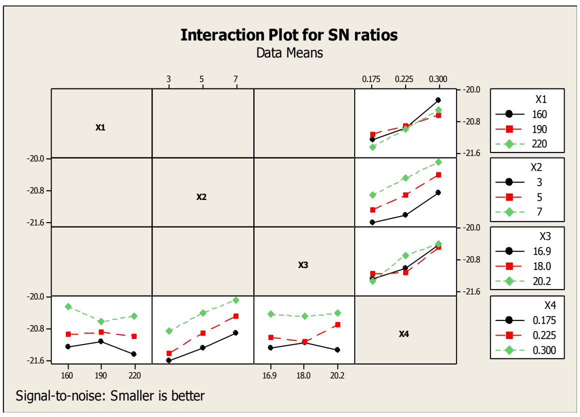

Figure 2b: Interaction effects Plot for S/N ratio

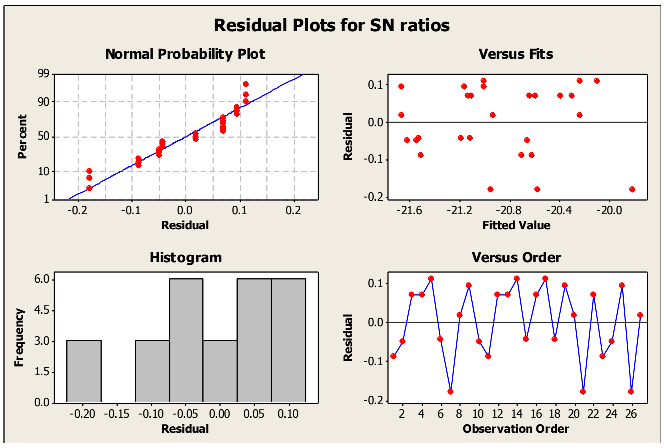

Figure 3: Residual Plots For S/N Ratio

Genetic Algorithm (GA)

In the early of 1970s, the Genetic algorithm (GA) concept is developed by Holland and his colleagues from the Darwin's evolutionary theory. It explains about the fitness for survival theory. It is inspired by the Darwin's evolutionary theory, which explains the origin of species. In nature, weak and unfit species within their environment are faced with extinction by natural selection. The strong ones have greater opportunity to pass their genes to future generations via reproduction. In the long run, species carrying the correct combination in their genes become dominant in their population. Sometimes, during the slow process of evolution, random changes may occur in genes. If these changes provide additional advantages in the challenge for survival, new species evolve from the old ones. Unsuccessful changes are eliminated by natural selection. This concept is applied in the real world problems to get feasible, optimized solution.

Multi Objective Optimisation

Optimizing a problem means finding a set of decision variables which satisfies constraints and optimizes simultaneously a vector function. The elements of the vector represent the objective functions of all decision makers. This vector optimization leads to a non-unique solution of the problem. In this research work, more than one objective function involves to determine the output quality of the weld bead. In this paper, without loss of generality, the minimization of two objectives and maximization of one objective, all equally important has been analyzed.

Let X be the design space for the decision vector $\vec{x}$ which is in the form $\vec{x} = (x_1, x_{2,} \ldots, x_n)$. The evolution theory yields a solution $\vec{y} = (y_1, y_2)$ in the objective space Y i.e. f: X → Y is a vector map of the form. But the decision vector $\vec{x_1}$ and $\vec{x_2}$ requires a dominance criteria to get better solution. This dominance may be very well solved by Pareto criteria. This criteria states that an objective vector $\vec{y_1}$ is said to dominate another objective vector $\vec{y_2}$ (ie., $\vec{y_1} < \vec{y_2}$) if no component of $\vec{y_1}$ is greater than the corresponding components $\overrightarrow{y_2}$ of and at least one component is greater. Accordingly, the solution $\overrightarrow{x_1}$ dominates $\overrightarrow{x_2}$, if $f(\overrightarrow{x_1})$ dominates $f(\overrightarrow{x_2})$. All non-dominated solutions are the optimal solutions of the problem, solutions not dominated by any others. The set of these solutions is named Pareto set while its image in objective space is named Pareto front (Shown in Figure 4).

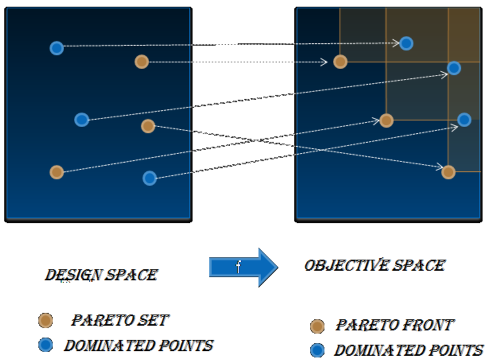

Figure 4: Pareto front

Formulation of Fitness Function

In the present work , the weld bead geometry such as weld bead width, weld bead reinforcement and weld bead penetration are the three output responses which conflicts in nature. In the process of optimization, the objective is to minimize the bead width, minimize the reinforcement and maximize the penetration. Using Taguchi techniques and multiple regression analysis, the developed empirical values (Thamilarasi et al, 2015) are given below. The objective equations are optimized subject to feasible bounds of input variables.

Minimize

BW = 13.4954 + 0.07148 Arc current + 0.25958 Stick out +0.00649 Arc voltage – 48.9008 Travel speed (5)

Minimize

BH = – 0.608578 + 0.01487 Arc current + 0.13548 Stick out – 0.00024044 Arc voltage – 8.84251169 Travel speed (6)

Maximize

BP = 14.06574 + 0.003195 Arc current – 0. 25824 Stick out – 0.041272006 Arc voltages – 8. 4275321 Travel speed (7)

Subjected To Constraints

16.9 Volts $\leq$ V $\geq$ 20.2 Volts; 0.175 mm/min $\leq$ S $\geq$ 0.3 mm/min

160 Amps $\leq$ I $\geq$ 220 Amps; 3 mm $\leq$ H $\geq$ 7 mm

The control parameters required for implementation of the genetic algorithm are listed in Table 6

Using the MATLAB GA optimization toolbox, multiple runs of the algorithm have been carried out at different settings and the optimum results are given in Figure 5. The corresponding optimum process parameters are arc current is 166 Amps, stick out is 3 mm, arc voltage is 18.3 Volts and travel speed is 0.3 mm/min

Table 5: GA control Parameters

Sl.No	Control Parameters	Value
1	Population Size	100
2	Number of Generations	112
3	Cross over Probability	0.8
4	Mutation Probability	0.5

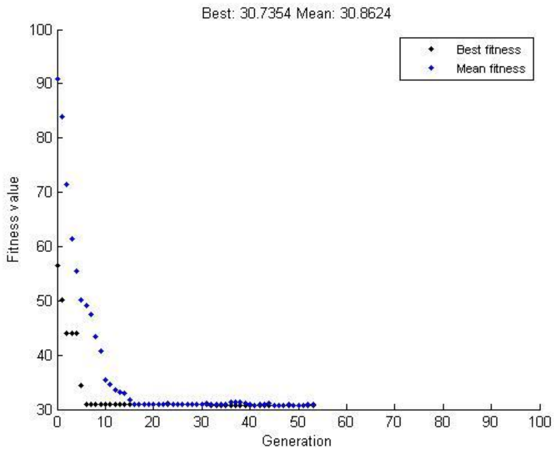

Figure 5: Optimum Results From GA

Conformation Test

The confirmatory experiments are conducted for the optimal parameters obtained parameters obtained from the MATLAB GA and listed in Table 6

Table 6: Confirmation Test Result And Its Error Between Optimum Value

		Confirmation test (Original Value)			**Optimum value from GA**
		Trial 1	**Trial 2**	**Trial 3**	
Input parameters	Arc current (Amps)	160	160	160	160
	Stick out (mm)	3	3	3	3
	Arc voltage (Volt)	20.2	20.2	20.2	20.2
	Travelling Speed (mm)	0.3	0.3	0.3	0.299
Output response	Bead width (mm)	20.8525	20.0125	20.062	19.5473
	Bead Reinforcement (mm)	1.4275	1.495	1.472	1.502
	Bead penetration (mm)	9.995	10.265	10.093	9.615
Error %	Bead width (mm)	6.26%	2.32	2.57	3.71643183
	Bead Reinforcement (mm)	-5.22%	-0.47	-2.04	-2.5750617
	Bead penetration (mm)	3.80	6.33	4.74	4.95668445

The Average prediction error for bead width is 3.71%, for bead reinforcement is 2.57% and for bead penetration is 4.95%. Thus the GA predicted results are within the acceptable limits (<95% Confidence interval), so the predicted model is found satisfactory for robotic gas metal arc welding process. The screen shot for the results using MATLAB optimization tool box is given in Figure 6

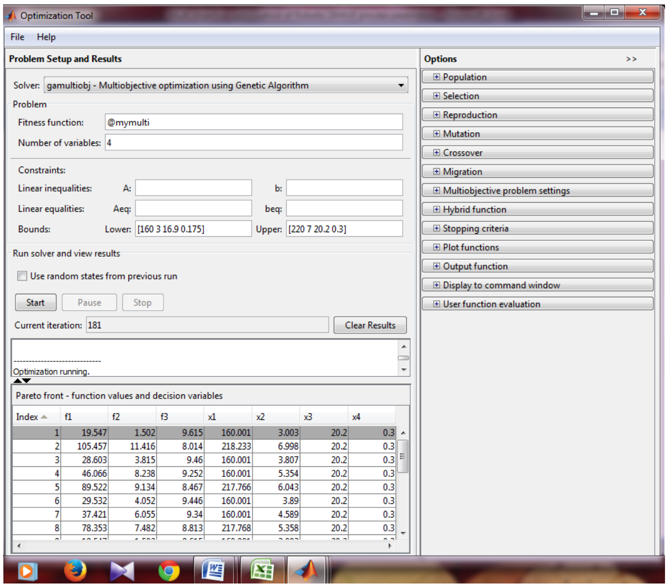

Figure 6: Screenshot Of Multi-Objective Optimization Using GA

Conclusion

An attempt to optimize the processing parameters in robotic gas metal arc welding of structural steel IS 2062 E250BR using genetic algorithm was done.It was intended to obtain minimum bead width, minimum reinforcement and maximum penetration of a weld bead simultaneously. The empirical model developed using multiple regression analysis was used as objective function for multi objective optimization using genetic algorithm. It is evident from the validation experiments results has maximum of 4.95% error and minimum of 2.5% error. Thus, for the programmer/welder can very well use this model to improve quality of the product by selecting the optimal level easily.

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