

Application of Imperialist Competitive Algorithm in Optimizing the Width of Heat Affected Zone in GMAW Process

Masood Aghakhani, Maziar Mahdipour Jalilian, Mohammad Mehdiabadi, Mahyar Mahdipour Jalilian, and Alimohammad Karami

Abstract—In Gas Metal Arc Welding (GMAW) process, one of the main goals is to reach minimum width of Heat affected Zone (HAZ) as a characteristic of quality. A five level five factor rotatable central composite design was used to collect the data for width of HAZ. After collecting the data, the regression equation of width of HAZ was obtained as a function of wire feed rate, welding voltage, nozzle-to-plate distance, welding speed and gas flow rate using least squares method. Then the cost function (width of HAZ) was minimized by using the Imperialist Competitive Algorithm. The computational result demonstrates that the proposed optimization algorithm is quite effective in minimizing the cost function. The result shows that in order to obtain lower width of HAZ, wire feed rate and welding voltage must be at their lowest levels while nozzle-to-plate distance, welding speed and gas flow rate should be at their highest levels.

Index Terms—Gas Metal Arc Welding (GMAW), width of HAZ, Characteristic of Quality, Rotatable Central Composite Design, Imperialist Competitive Algorithm.

I. INTRODUCTION

The Gas Metal Arc Welding process is a welding method that yields coalescence of materials by heating with a welding arc between continuous filler metal (consumable) electrode and the workpiece [1]. Increasing quality and productivity of GMAW process is the main goal of the most researchers. In this connection, it is necessary to control the welding input variables in order to reach minimum width of HAZ. The width of HAZ of weld bead is shown in Fig. 1. In this paper a cost function namely $F = \text{width of HAZ}$, has been considered and the goal is to minimize this function in order to reach the minimum width of HAZ. Using design of experiments can be an efficient procedure for collecting data by conducting minimum number of experiments. This has led to saving of

cost and time and, therefore increasing productivity. Thus, in the present research work an attempt was made to make use of five-levels five-factors rotatable central composite design for generating the experimental data with the objective of optimizing weld bead penetration in gas metal arc welding process. For this purpose the effects of wire feed rate (W), welding voltage (V), nozzle-to-plate distance (N), welding speed (S) and gas flow rate (G) on the width of HAZ were investigated using a regression equation between input and output variables. Subsequently, the regression equation obtained was used for optimizing by the Imperialist Competitive Algorithm. The welding process variables and their limits have been given in table I.

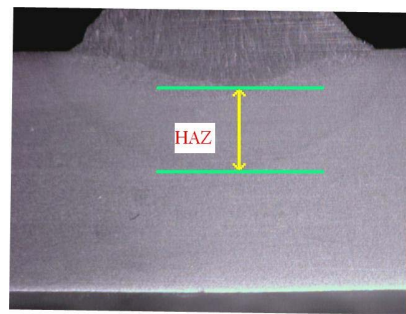


Fig 1. Width of HAZ

II. DESIGN OF EXPERIMENTS

Design of experiments (DOE) is a powerful technique used for exploring new processes, gaining increased knowledge of the existing processes and optimizing these processes for achieving world class performance [2]. Research and development are the heart and soul of improvement efforts in manufacturing, and it's fast becoming standard practice to employ design of experiments methods in industrial R&D. In the early stages of their work, experimenters typically use screening experiment designs that normally consist of trials run at the extreme lower- and upper-bound level setting combinations of the variable study ranges. They provide information on the direct additive effects of the study variables and on pair-wise (two-variable) interaction effects. Screening designs enable experimenters to select the best materials and equipment from available alternatives and to focus on the correct variables and ranges for further study. In the later stages of the experimental work, the goal shifts from screening to product and process optimization. The statistical experiment designs most widely used in optimization experiments are termed "response surface designs." In

Manuscript received April 30, 2011; revised July 30, 2011.

M. Aghakhani is with the Department of Mechanical Engineering, Faculty of Engineering at the University of Razi, Kermanshah, Iran (phone: +988314274535-8; fax: +988314283263; e-mail: aghakhani@razi.ac.ir).

Maziar M. Jalilian is with Department of Mechanical Engineering, Faculty of Engineering at the University of Razi, Kermanshah, Iran (e-mail: maziar.1986.2000@gmail.com).

M. Mehdiabadi is with Department of Mechanical Engineering, Faculty of Engineering at the University of Razi, Kermanshah, Iran (e-mail: M.mehdiabadi@hotmail.com).

Mahyar M. Jalilian is with Department of Chemical Engineering, Faculty of Engineering at the University of Razi, Kermanshah, Iran (e-mail: mahyar390625@gmail.com).

A. Karami is with Department of Mechanical Engineering, Faculty of Engineering at the University of Razi, Kermanshah, Iran (e-mail: alimohammad.karami@yahoo.com).

addition to trials at the extreme level settings of the variables, response surface designs contain trials in which one or more of the variables is set at the midpoint of the study range (other levels in the interior of the range may also be represented). Thus, these designs provide information on direct effects, pair wise interaction effects and curvilinear variable effects. Response surface methodology, one approach to product and process optimization work, derives its name from the use of these widely used optimization experiment designs. Most practitioners of RSM now generate their experiment designs and analyze their data using a statistical software program running on a personal computer. Many of these software programs can generate many classes of RSM designs and, in some cases, offer several varieties of each class. However, the central composite design is the most popular of the many classes of RSM designs due to the following three properties:

A CCD can be run sequentially. It can be naturally partitioned into two subsets of points; the first subset estimates linear and two-factor interaction effects while the second subset estimates curvature effects. The second subset need not be run when analysis of the data from the first subset points indicates the absence of significant curvature effects.

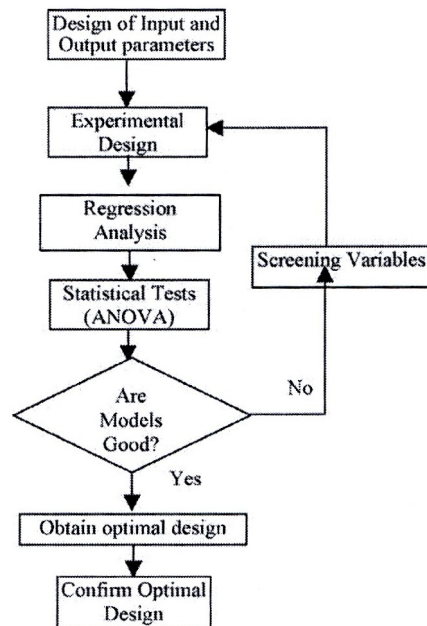


Fig 2. Procedure of response surface methodology[3]

CCDs are very efficient, providing much information on experiment variable effects and overall experimental error in a minimum number of required runs. CCDs are very flexible. The availability of several varieties of CCDs enables their use under different experimental regions of interest and operability. Three main varieties of CCD are available in most statistical software programs: face-centered, rotatable and inscribed. Many experimenters are uncertain about the best variety to use in a given study. To make the right selection, the experimenter must first understand the differences between these varieties in terms of the experimental region of interest and region of operability, according to the following definitions[3].

Region of interest --a geometric region defined by lower and upper limits on study-variable level setting combinations that are of interest to the experimenter [3].

Region of operability --a geometric region defined by lower and upper limits on study-variable level setting combinations that can be operationally achieved with acceptable safety and that will output a testable product [3].

Rotatable central composite design as a technique of DOE can be used to collect, model and optimize the output data. In this research work, thirty two experiments were conducted as per design matrix given in table II.

The response surface method is a sequential process and its procedure can be summarized as shown in Fig. 3.

III. EXPERIMENTAL PROCEDURE



Fig 3. The experimental setup

After selecting the central composite design, experiments were performed by means of a MIG welding machine using direct current electrode positive (DCRP). Test pieces of size 200 mm x 100 mm x 6 mm were cut from steel plates. Filler wire (ER70S-6) in the form of coil of 0.8 mm diameter was used for depositing the weld beads. The chemical composition of the base metal and filler wire are given in table III and table IV respectively. The experimental setup as shown in Fig. 3 consisted of three parts, welding power source, wire feed unit and the welding manipulator where the welding gun was held in a frame mounted above the work table directly on it, and it was provided with an attachment on the manipulator for both up and down movement for setting the required nozzle-to-plate distance. The bead-on-plate technique was adopted for welding the test pieces. The shielding gas composition was Argon 80% and CO₂ 20%. Then the test pieces were cut perpendicular to weld bead by a cutting machine shown in Fig. 4. After that the pieces were polished by suitable apparatus shown in Fig. 5 and Fig. 6 and finally etched by a 2% nital solution which the test piece is shown in Fig. 7. Then the depth of penetration and width of heat affected zone were measured using a microscope shown in Fig. 8. The measures were collected for each experiment at last.



Fig 4. Cutting machine



Fig 5. Primary polishing apparatus



Fig 6. Secondary polishing apparatus



Fig 7. Polished test piece



Fig 8. Microscope used for measurement

IV. IMPERIALIST COMPETITIVE ALGORITHM

Imperialist Competitive Algorithm (ICA) is an algorithm for optimizing inspired by the imperialistic competition. Like other evolutionary ones, the proposed algorithm starts with an initial population. Population individuals called country are in two types: colonies and imperialists that all together form some empires. Imperialistic competition among these empires forms the basis of the proposed evolutionary

algorithm. During this competition, weak empires collapse and powerful ones take possession of their colonies. Imperialistic competition hopefully converges to a state in which there exists only one empire and its colonies are in the same position and have the same cost as the imperialist [5]. Using this algorithm, one can find the optimum condition of the most functions. In this connection, the proposed model based on regression analysis is then embedded into the ICA to optimize the objective function.

The goal of optimization algorithms is to find an optimal solution in terms of the variables of the problem. We form an array of variable values to be optimized. In Genetic Algorithm terminology, this array is called “chromosome”, but here the term “country” is used for this array. In an N_{var} -dimensional optimization problem, a country is a $1 \times N_{var}$ array. This array is defined by $country = [p_1, p_2, p_3, \dots, p_{N_{var}}]$. The variable values in the country are represented as floating point numbers. The cost of a country is found by evaluating the cost function (f) at the variables $p_1, p_2, p_3, \dots, p_{N_{var}}$. Then $cost = f(country) = f(p_1, p_2, p_3, \dots, p_{N_{var}})$ [5].

To start the optimization algorithm we generate the initial population of size N_{pop} . We select N_{imp} of the most powerful countries to form the empires. The remaining N_{col} of the population will be the colonies each of which belongs to an empire. Then we have two types of countries; imperialist and colony. To form the initial empires, we divide the colonies among imperialists based on their power. That is the initial number of colonies of an empire should be directly proportionate to its power. To divide the colonies among imperialists proportionally, we define the normalized cost of an imperialist by $C_n = c_n - \max\{c_i\}$. Where c_n is the cost of n^{th} imperialist and C_n is its normalized cost. Having the normalized cost of all imperialists, the normalized power of each imperialist is defined by [5]

$$P_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right| \quad (1)$$

From another point of view, the normalized power of an imperialist is the portion of colonies that should be possessed by that imperialist. Then the initial number of colonies of an empire will be [5]

$$N.C_n = \text{round} \{ p_n . N_{col} \} \quad (2)$$

where $N.C_n$ is the initial number of colonies of n^{th} empire and N_{col} is the number of all colonies. To divide the colonies, for each imperialist we randomly choose $N.C_n$ of the colonies and give them to it. These colonies along with the imperialist will form n^{th} empire [5].

As mentioned, imperialists countries started to improve their colonies. We have modeled this fact by moving all the colonies toward the imperialist. This movement is shown in Fig. 9, in which the colony moves toward the imperialist by x units. The new position of colony is shown in a darker color. The direction of the movement is the vector from colony to imperialist. In this figure x is a random variable with uniform (or any proper) distribution. Then for x we have

$$x \sim U(0, \beta \times d) \quad (3)$$

where β is a number greater than 1 and d is the distance between colony and imperialist. A $\beta > 1$ causes the colonies to get closer to the imperialist state from both sides.

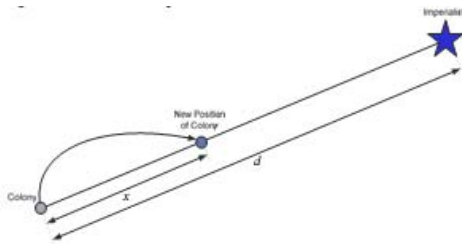


Fig 9. Moving colonies toward their relevant imperialists [5].

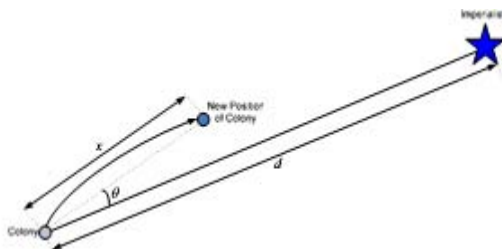


Fig 10. Moving colonies toward their relevant Imperialist in a randomly deviated direction.

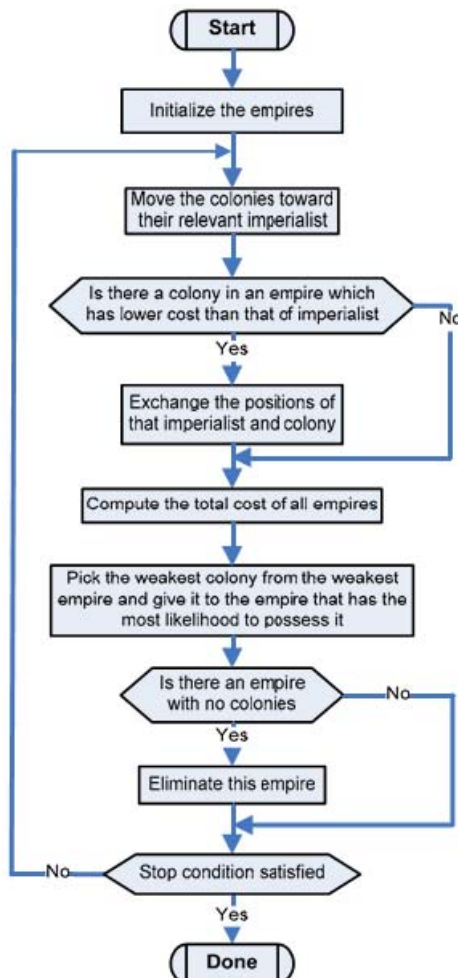


Fig 11. Flowchart of the proposed Algorithm [5]

To search different points around the imperialist we add a random amount of deviation to the direction of movement. Fig. 10 shows the new direction. In this figure θ is a random

number with uniform (or any proper) distribution. Then

$$\theta \sim U(-\gamma, \gamma) \quad (4)$$

where γ is a parameter that adjusts the deviation from the original direction. Nevertheless the values of β and γ are arbitrary, in most of our implementation a value of about 2 for β and about $\pi/4$ (Rad) for γ have resulted in good convergence of countries to the global minimum.

Briefly, one can observe ICA procedure as shown in Fig.11.

More information can be found at [4].

TABLE I. WELDING VARIABLES AND THEIR LIMITS.

	Notation	Coding					Units
Variable		-2	-1	0	+1	+2	
Wire feed rate	W	8	9	10	11	12	m/min
Arc voltage	V	26	28	30	32	34	volts
Nozzle-to-plat e-distance	N	12	14	16	18	20	mm
Welding speed	S	20	23.5	27	30.5	34	cm/min
Gas flow rate	G	10	12	14	16	18	lit/min

TABLE II. DESIGN MATRIX

No.	W	V	N	S	G	HAZ(mm)
1	1	-1	1	-1	1	2.60
2	1	1	1	-1	-1	2.75
3	1	1	1	1	1	2.70
4	0	0	0	2	0	1.51
5	-1	1	-1	-1	-1	2.21
6	1	1	-1	1	-1	3.41
7	-1	-1	-1	-1	1	1.49
8	1	-1	1	1	-1	2.26
9	0	0	0	0	0	2.29
10	-1	-1	1	1	1	1.23
11	1	-1	-1	1	1	2.15
12	0	0	0	0	0	2.30
13	-1	1	1	1	-1	1.85
14	0	0	0	0	0	2.29
15	0	0	0	0	0	2.26
16	0	2	0	0	0	2.74
17	0	0	0	0	0	2.40
18	-2	0	0	0	0	1.46
19	2	0	0	0	0	3.30
20	-1	-1	-1	1	-1	1.28
21	0	-2	0	0	0	1.90
22	0	0	0	0	-2	2.79
23	0	0	0	-2	0	2.94
24	-1	1	1	-1	1	2.15
25	-1	1	-1	1	1	2.42
26	-1	-1	1	-1	-1	2.68
27	0	0	2	0	0	2.02
28	1	1	-1	-1	1	3.54
29	1	-1	-1	-1	-1	3.30
30	0	0	-2	0	0	2.61
31	0	0	0	0	0	2.40
32	0	0	0	0	2	2.21

TABLE III. THE CHEMICAL COMPOSITION OF STEEL ST37

Element	Cr	P	S	Si	Ti	Mn	C	Fe
w%	0.03	0.00	0.0	0.02	0.00	0.41	0.11	Bal
	1	7	1	4	2	7	3	

TABLE IV. THE CHEMICAL COMPOSITION OF FILLER WIRE

Element	C	Si	P	S	Al	Cu	Mn	Fe
w%	0.07-0.19	0.65-0.85	<0.025	0.035	0.5-0.9	>0.5	1-1.5	Bal

V. RESULTS AND DISCUSSION

After collecting data, and applying the least squares method, the regression equation was obtained as below:

$$\text{HAZ} = 2.32 + 0.462 W + 0.239 V - 0.115 N - 0.261 S - 0.109 G - 0.162 WN - 0.167 VN + 0.180 VS + 0.164 VG - 0.0538 NS + 0.0187 WW - 0.0202 SS + 0.0475 GG \quad (5)$$

$$R^2 = 98.0\% \quad \& \quad R^2_{adj} = 96.5\% \quad (6)$$

After that, the regression equation was minimized by the ICA.

In this algorithm, number of total countries, number of initial imperialist countries, number of decades and revolution rate were 100, 10, 50, 0.2 respectively. The results of minimization are shown in table V.

TABLE V. THE RESULTS OF MINIMIZATION

W	V	N	S	G	HAZ(mm)
-2	-2	+2	+2	+2	0.143

VI. CONCLUSIONS

In this paper, experiments were carried out as per central composite design for generating data to be used by regression analysis for determining the input-output relationship of the Gas Metal Arc Welding (GMAW) process. The effect of five main welding variables in the gas metal arc welding process such as wire feed rate, arc voltage, nozzle-to-plate distance, welding speed and gas flow rate on the width of HAZ were investigated. The Imperialist Competitive Algorithm was utilized to minimize the width of HAZ. The result shows that in order to obtain the lower width of HAZ, wire feed rate and arc voltage must be at their lowest levels and nozzle-to-plate distance, welding speed and gas flow rate at their highest levels.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support from the University of Razi, Kermanshah, Iran.

REFERENCES

- [1] H. Ates, "Prediction of gas metal arc welding parameters based on artificial neural networks," *Journal of Materials & Design* 28. pp. 2015-2023, 2007.
- [2] J. Antony, "Design of Experiments for Engineers and Scientists" ISBN: 0750647094, Elsevier Science & Technology Books, October 2003.
- [3] <http://www.qualitydigest.com/june01/html/doi.html>
- [4] H.K.Kansal, S.Singh, P.Kumar, "Parametric optimization of powder mixed electrical discharge machining by response surface methodology," *Journal of Materials Processing Technology* 169. pp. 427-436, 2005.
- [5] E. Atashpaz-Gargari, C. Lucas, "Imperialist competitive algorithm: An algorithm for optimization inspired by imperialistic competition," *IEEE Congress on Evolutionary Computation*, Singapore, 2007.
- [6] J. Powell, P.S. Henry, W.M. Steen, "Laser cladding with preplaced powder: analysis of thermal cycling and dilution effects," *Surf. Eng.* pp. 141-149, 1988.
- [7] Jae-Do Kim, Yun Peng, "Melt pool shape and dilution of laser cladding with wire feeding," *Journal of Materials Processing Technology* 104. pp. 284-293, 2000.
- [8] V. Gunaraj, N. Murgan, "Prediction of heat affected zone characteristics in submerged arc welding of structural steel pipes," *Welding Journal*, pp. , January 2002.



Masood Aghakhani is an assistant professor in the Department of Mechanical Engineering, Faculty of Engineering, University of Razi, Iran. Masood was born in April 1958 in Nahavand, Iran. He received his B.E. degree in Mechanical Engineering from Regional Engineering college srinagar, Kashmir, India. He then continued his graduate studies in India and graduated with M.E. and Ph.D. degrees in production and industrial Engineering from Delhi College of Engineering, University of Delhi, India 1995.

Dr aghakhani's research interest include manufacturing (welding) processes optimization and applications of heuristic algorithms in industrial optimization.



Maziar Mahdipour Jalilian was born in July 1986 in Kermanshah. He obtained his B.E. degree in Mechanical Engineering from Khaje Nasir-e -Din Tousi University of Technology, Tehran, Iran in 2008. He also has obtained his Master Degree under the supervision of Dr. Aghakhani, at the Department of Mechanical Engineering, University of Razi, Kermanshah, Iran, in 2011.