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Optimization of Bead Geometry in Submerged Arc Welding Process Using Imperialist Competitive Algorithm

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ABSTRACT

The Imperialist Competitive Algorithm (ICA) that was recently introduced has shown its good performance in optimization problems. This algorithm is inspired by competition mechanism among Imperialists and colonies, in contrast to evolutionary algorithms. This paper presents the mathematical modeling and optimization of bead geometry in submerged arc welding using of regression analysis and ICA. Generally, in welding process, weld bead geometry and weld quality are, in most parts, depend on welding parameters, thus the weld quality is usually measured in terms of weld bead geometry which that includes weld height, width and penetration. Therefore, in this study, an attempt was made to minimize the weld area, after satisfying the condition of maximum bead penetration using of Imperialist Competitive Algorithm. ICA has demonstrated excellent capabilities such as simplicity, accuracy, faster convergence and better global optimum achievement. The results of ICA were finally compared with the Genetic Algorithm (GA). The outcome shows the success of ICA in optimizing the weld bead geometry.
KEYWORDS: Imperialist competitive algorithm- submerged arc welding

INTRODUCTION

Welding is one of the most useful methods for permanently joining of parts and is extremely important in the industry. Among a wide variety of welding processes, submerged arc welding is more taken into account based on the multiple benefits such as accepted quality and high deposition rate. Like other methods, the quality of welds in submerged arc welding is directly affected by weld bead geometry which includes the bead height, width and penetration. In this regard, the proper adjustment of input parameters is an unavoidable necessity in order to achieve the joints with desired geometric properties due to the vastness and variety of involved parameters. Investigation into the relationship between the welding parameters and the bead geometry began in the mid -1900s. Lee and Um [1] reported some of the first works in which regression analysis was applied to welding geometry research. In last decade, several trials were made by various researchers to analyze different welding processes using of regression method. Kim et al [2,3] used regression analysis for modeling the Gas Metal Arc Welding (GMAW) process and discussed the effects of process parameters on the weld bead-geometric parameters. Ganjigatti et al.[4] established input-output relationships in Metal Inert Gas (MIG) welding process through regression analysis; Xue et al. [5]applied fuzzy regression method for proper prediction of process variables in the robotic arc-welding process. Most of the work reported on the optimization of weld bead geometry is directed to Genetic Algorithm (GA).Vasudevan et al. [6] used a Genetic Algorithm (GA) based computational approach to obtain the target bead geometry in Tungsten Inert Gas welding (TIG) of stainless steel by optimizing the input variables. In another work, Nagesh and Datta[7] was applied genetic algorithm for optimization of welding parameters to achieve desired height to width ratio in TIG welding process. A binary-coded genetic algorithm was used by Dey et al. [8] to optimize bead geometry in electron beam welding.

In 2007, Atashpaz-Gargari and Lucas[9] introduced the basic idea of Imperialist Competitive Algorithm (ICA) to solve the real world engineering and optimization problems. Imperialist Competitive Algorithm is a new meta-heuristic optimization developed based on a socio-politically motivated strategy and contains two main steps: the movement of the colonies and the imperialistic competition. From the basis of the ICA the powerful imperialists are reinforced and the weak ones are weakened and gradually collapsed, directing that algorithm towards optimum points. This algorithm has been successfully applied to solve some engineering

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problems in recent years, some of those are mentioned below. In Atashpaz-Gargari et al.[10], ICA is used to design an optimal controller which not only decentralizes but also optimally controls an industrial Multi Input Multi Output (MIMO) distillation column process. Biabangard-Oskouyi et al.[11] used ICA for reverse analysis of an artificial neural network in order to characterize the properties of materials from sharp indentation test. Nazari et al.[12] solved the integrated product mix-outsourcing (which is a major problem in manufacturing enterprise) using ICA. Kaveh and Talatahar [13] utilized the ICA to optimize design of skeletal structures. Yousefi et al. [14] presented the application of Imperialist Competitive Algorithm for optimization of cross-flow plate fin heat exchanger. They concluded that ICA comparing to the traditional GA shows considerable improvements in finding the optimum designs in less computational time under the same population size and iterations. Mozafari et al.[15] applied ICA to optimize intermediate epoxy adhesive layer which is bonded between two dissimilar strips of material. They compared the results of ICA with the Finite Element Method (FEM) and Genetic Algorithm; they showed the success of ICA for designing adhesive joints in composite materials.

In this paper, the basic idea of Imperialist Competitive Algorithm (ICA) is introduced, bead geometry in submerged arc welding is modeled, input variables are optimized and compare is made against GA method. Interested readers may refer to [16], for a detailed discussion on the principle of the GA.

2. Imperialist competitive algorithm

The proposed algorithm mimics the social–political process of imperialism and imperialistic competition. ICA contains a population of agents or countries. The pseudo-code of the algorithm is as follows.

2.1. Step1: Initial empires creation

Comparable to other evolutionary algorithms, the proposed algorithm starts by an initial population. An array of the problem variables is formed which is called Chromosome in GA and country in this algorithm. In a N_{var}-dimensional optimization problem a country is a $1_{\times}$ N_{var} array which is defined as follows:

$$Country = [P_1, P_2, P_3, ..., P_{N\,var}] \quad (1)$$

A specified number of the most powerful countries, N_{imp}, are chosen as the imperialists and the remaining countries, N_{col}, would be the colonies which are distributed among the imperialists depending on their powers which is calculated using fitness function. The initial empires are demonstrated in Fig.1where more powerful empires have greater number of colonies.

Fig.1. Generating the initial empires: The more colonies an imperialist possess, the bigger is its relevant mark.

2.2. Step 2: Assimilation policy

To increase their powers, imperialists try to develop their colonies through assimilation policy where countries are forced to move towards them. A schematic description of this process is demonstrated in Fig.2.

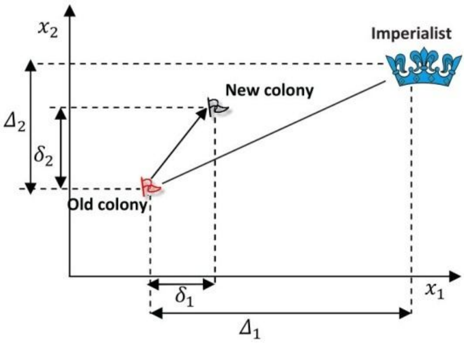


Fig. 2.Movement of colonies toward their relevant imperialist

The colony is drawn by imperialist in the culture and language axes (analogous to any dimension of problem). After applying this policy, the colony will get closer to the imperialist in the mentioned axes (dimensions). In assimilation, each colony moves with a deviation of θ from the connecting line between the colony and its imperialist by x units to increase the search area, where θ and x are random numbers with uniform distribution and β is a number greater than one and d is the distance between the colony and the imperialist state. $\beta > 1$ causes the colonies to get closer to the imperialist state from both sides.

$$\chi \sim U(0, \beta \times d) \quad (2)$$

$$\theta \sim U(-\gamma, \gamma) \quad (3)$$

2.3. Step 3: Revolution

In each decade (generation) certain numbers of countries go through a sudden change which is called revolution. This process is similar to mutation process in GA which helps the optimization process escaping local optima traps.

2.4. Step 4: Exchanging the position of imperialist and colony

As the colonies are moving towards the imperialist and revolution happens in some countries, there is a possibility that some of these colonies reach a better position than their respective imperialists. In this case the colony and its relevant imperialist change their positions. The algorithms will be continued using this new country as the imperialist.

2.5. Step 5: Imperialistic competition

The most important process in ICA is imperialistic competition in which all empires try to take over the colonies of other empires. Gradually, weaker empires lose their colonies to the stronger ones. This process is modelled by choosing the weakest colony of the weakest empire and giving it to the appropriate empire which is chosen based on a competition among all empires. Fig.3. demonstrates a schematic of this process.

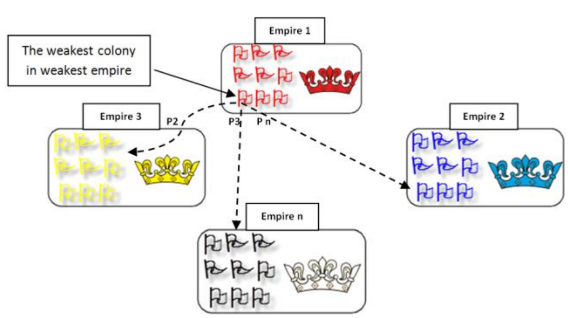


Fig. 3.Imperialistic competition: The more powerful an empire is, the more likely it will possess the weakest colony of the weakest empire.

In this figure empire 1 is considered as the weakest empire, where one of its colonies is under competition process. The empires 2 to *n* are competing for taking its possession. In order to begin the competition, firstly, the possession probability calculated considering the total power of the empire which is the sum of imperialist power and an arbitrary percentage of the mean power of its colonies. Having the possession probability of each empire a mechanism similar to Roulette Wheel is used to give the selected colony to one of the empires considering a proportional probability.

2.6. Step 6: Convergence

Basically the competition can be continued until there would be only one imperialist in the search space, However, different conditions may be selected as termination criteria including reaching a maximum number of iterations or having negligible improvement in objective function. Fig.4. depicts a schematic view of this algorithm. Whenever the convergence criterion is not satisfied, the algorithm continues.

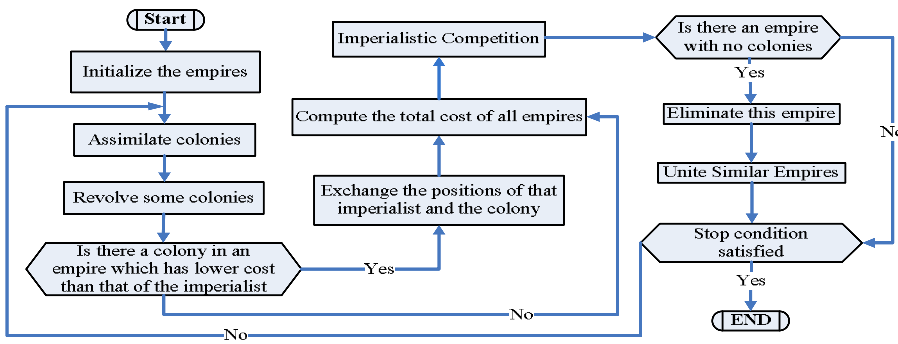


Fig.4. Flowchart of the Imperialist Competitive Algorithm

The main steps of ICA is summarized in the pseudo-code are given in Fig.5. The continuation of the mentioned steps will hopefully cause the countries to converge to the global minimum of the cost function. Different criteria can be used to stop the algorithm.

1-Initialization
    1-1-Set Parameters (Pop Size, Number of imperialist, ξ , P-Revolution, % Assimilate)
    1-2-Generating initial Countries (Randomly)
2-Evaluate fitness of each country
3-Form initial empires
    3-1-Choice power countries as imperialists
    3-2-Assigne other countries (colonies) to imperialists based on their power
4-Move the colonies of an empire toward the imperialist (assimilation)
5-Revolution among colonies and imperialist
6- If the cost of colony is lower than own imperialist
    6-1-Exchanging positions of the imperialist and a colony
7- Calculate Total power of the empires.
8-Imperialistic competition
    8-1- Select the weakest colony of the weakest empire and assign this to one of the strange empires
9-Eliminate the powerless empires (the imperialist with no colony)
10-Stop if stopping criteria is met, otherwise go to step 4.

Fig.5. Pseudo code of the Imperialistic Competitive Algorithm

3 -RESEARCH METHOD

In submerged arc welding, the weld bead geometry is influenced by numerous variables including the welding current, type and polarity of electric current, welding voltage, speed of welding, chemical composition of work piece, and electrode and welding powder. According to the diversity of variables affecting the output of process, it is clear that investigating the effect of all parameters simultaneously requires the high cost and time. Although it is better to design the tests based on the investigation technique of all parameters in ideal state and in order to observe the effect of variables, all conducted research include a kind of designing the tests for systematic numeration of a small number of parameters. In this study, the variables of work piece, electrode welding powder have been ignored in order to reduce the examined parameters. Moreover, the measures have been adopted for some of the parameters in order to ignore them by reducing the impact. This case clarifies the necessity for applying the advanced methods in designing the tests. Based on the conducted studies, 3^K factor method is a common method in designing the experiment for parameters with three variables each which are effective at three levels. Three impact levels as low (0), middle (1) and high level (2) are determined. In this study, three parameters of welding current (I), speed (S) and welding voltage (V) have been considered as the input variables and thus the number of experiments has been obtained 27. Table 1 represents the values of input variables of experimental tests.

Table 1 - Input test

Voltage (V)	Speed (cm/min)	Welding current (A)	Level
26	17.40	490	0
32	18.50	640	1
37	19.70	720	2

After doing the welding, venire caliper with resolution 0.02 mm has been used in order to evaluate the weld bead width (BW) and height (BH). Moreover, the parts have been holed by drilling machine and then measured in order to measure the bead penetration (BP). The results of these experiments are presented in the following table.

Table 2- experimental results

No.	I	V	S	BP(mm)	BW(mm)	BH(mm)
1	490	26	17.40	3.12	14.44	1.00
2	490	26	18.50	3.60	14.26	1.30
3	480	26	19.70	3.78	13.76	1.88
4	490	32	17.40	2.16	13.34	1.38
5	490	32	18.50	2.76	14.92	1.56
6	490	32	19.70	3.22	15.64	1.88
7	490	37	17.40	4.16	16.32	1.48
8	490	37	18.50	4.79	17.60	1.40
9	490	37	19.70	5.72	14.92	1.80
10	720	26	17.40	6.10	14.69	2.00
11	720	27	18.50	5.57	14.20	1.79
12	720	26	19.70	2.89	15.05	1.58
13	720	32	17.40	8.62	12.50	2.35
14	720	32	18.50	6.97	13.44	2.33
15	720	32	19.70	5.28	15.54	1.24
16	720	37	17.40	9.82	15.94	2.02
17	720	37	18.50	9.62	16.10	2.11
18	720	37	19.70	9.42	16.22	2.29
19	640	26	17.40	5.95	13.14	2.34
20	640	26	18.50	7.34	14.95	1.52
21	640	26	19.70	4.52	14.28	2.12
22	640	32	17.40	4.29	13.12	2.48
23	640	3 2	18.50	5.49	13.77	2.84
24	640	32	19.70	4.55	12.17	2.72
25	640	37	17.40	8.59	11.69	2.16
26	640	37	18.50	6.70	16.41	2.78
27	640	37	19.70	7.18	15.54	2.32

4. Problem statement and mathematical formulation

The aim of present study was to determine the set of optimal parameters of submerged arc welding process to ensure minimum weld area after satisfying the condition of maximum penetration. According to Dey et al.[8], the weld area can be obtained in terms of bead height, width and penetration (refer to Fig.6)

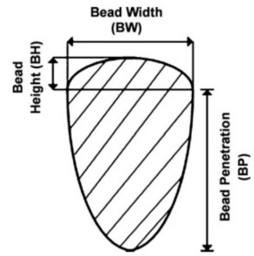


Fig.6- schematic illustration of weld geometry [8]

Based on the assumption that the weld area follows the parabolic curves, the above considered optimization problem can be mathematically stated as follows:

$$\text{Minimize: Weld area} = \frac{2}{3}\,(BH+BP)\;BW \tag{4}$$

Subject to the condition that BP takes the maximum value. In this study, the software SPSS has been used for modeling and regression analysis of weld bead variables (BP, BW, BH) in terms of process parameters (I, V, S). Based on the work of Karaoglu and Secgin [17], the mathematical model of weld bead parameters were considered due to higher accuracy as follows:

$$BH = \left(1.4978\frac{I^{0.6464}}{V^{0.7788}S^{0.4882}}\right) \tag{5}$$

$$BP = \left(0.0000235\frac{I^{1.7628}\,V^{0.4114}}{S^{0.0838}}\right) \tag{6}$$

$$BW = \left(0.0549\frac{I^{0.6005}\,V^{0.8174}}{S^{0.4729}}\right) \tag{7}$$

Substituting equations 5, 6 and 7 in equation 4 we have:

$$\text{Weld area} = \frac{2}{3}\left(\left(1.4978\frac{I^{0.6464}}{U^{0.7788}S^{0.4882}}\right) + \left(0.0000235\frac{I^{1.7628}\,V^{0.4114}}{S^{0.0838}}\right)\right)\left(0.0549\frac{I^{0.6005}\,V^{0.8174}}{S^{0.4729}}\right) \tag{8}$$

Equation 8 is cost function that aims to be minimized in this study.

5. RESULTS AND DISCUSSION

The Optimization problem is finding the process variables that minimize the weld area. ICA algorithm is used to optimize the weld area subject to the mentioned constraints. ICA parameters are selected based on Atashpaz-Gargari and Lucas [9] recommendations. β and γ values are set to 0.5 and π/4 respectively. Also, the ratio of initial imperialists to the initial countries is set to 0.1. To choose the proper number of countries for the optimization, the algorithm is executed for different number of initial countries and the respected results for the minimum total weld area. Due to the stochastic nature of the algorithm, each execution of the algorithm results in a different result, therefore in the entire study the best solution out of 10 executions is presented as the optimization result.

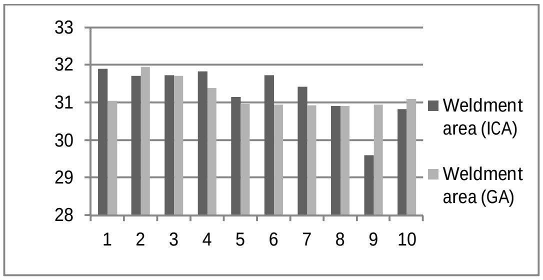
A careful investigation is carried out to compare the design efficiency of the proposed algorithm with traditional genetic algorithm (GA). An attempt was initially made to determine the minimum values of BH and BW and maximum value of BP by varying the input process parameters, that is, V, I, and S within their respective ranges. The following GA parameters were determined to yield the best results: probability of Mutation p_m=0.008; Population size N= 100; maximum number of generation G = 100. To be fair in the comparison, ICA parameters were considered as follow: Revolution Rate= 0.008; Assimilation coefficient= 0.5, Assimilation angle coefficient= 0.5, Initial Imperialists= 5, Zeta= 0.02 (Total Cost of Empire = Cost of Imperialist + Zeta * mean (Cost of All Colonies)); Population size=100, maximum number of iteration=100, similar to GA configurations. Both ICA and GA algorithms are programmed in MATLAB and run on an

AMD laptop, CPU A4 3305M 1.9GHz, RAM 4GB. It can be seen that ICA provides better results both in case of accuracy and computational time. The results are demonstrated in Table 3.

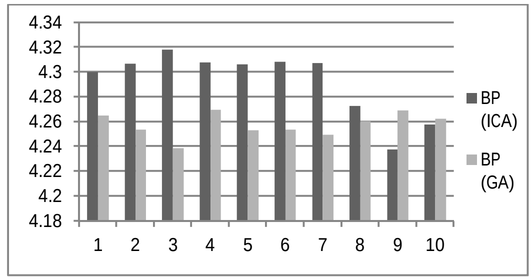
Table 3; Comparison of results from ICA and GA method

Parameters	Accelerating voltage	Beam current	Welding speed	CPU time (s)	Bead width (mm)	Bead height (mm)	Bead penetration (mm)	Minimum area of weld(mm^2)
ICA	26.4251	480.6052	18.7322	4	8.1921	1.51443	4.27129	31.28428
GA	26.2217	480.7776	18.8727	6	8.1151	1.51835	4.25754	31.1949

Since the minimum weld area after satisfying the condition of maximum weld penetration is desired, we compare the optimal weld area values and the maximum weld penetration in Fig 7(a) and(b) respectively. As it is illustrated in Fig 7-a, ICA can predict the minimum weld area as accurate as GA. According to Fig 7-b, it can be concluded that ICA is more successful for predicting the maximum weld bead penetration.



(a)



(b)

Figure 7 (a): The weld area (b): The weld bead penetration

6. Conclusions

In this study, three parameters including the current, speed and welding voltage were selected as the input variables and the weld bead penetration, width and height were modeled by the regression analysis. Then, Minimum weld area is considered as single objective function and imperialist competitive algorithm used for optimization of submerged arc welding process. According to the results, ICA algorithm comparing to the traditional GA shows considerable improvements in finding the optimum designs in less computational time under the same population size and iterations. Therefore, ICA can be applied in optimization of different welding process based in the desired objectives.

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