Application of Imperialist Competitive Algorithm to Optimization Problems Arising in Welding Process

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Abstract: The Imperialist Competitive Algorithm (ICA) that was recently been introduced has shown its superior performance in optimization problems. This algorithm is inspired by competition mechanism among Imperialists and colonies, in contrast to evolutionary algorithms. This paper presents optimization of bead geometry in welding process using ICA. Therefore, two case studies from literature are presented to show the effectiveness of the proposed 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 indicates the success of ICA in optimizing the weld bead geometry.

Keywords: Bead Geometry Optimization, Electron Beam Welding (EBW), Imperialist Competitive Algorithm, Submerged Arc Welding (SAW)

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1 INTRODUCTION

Welding is one of the most useful methods for permanently joining parts and is extremely important in industry. The quality of weld in welding process 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 unavoidably essential in order to achieve the joints with desired geometric properties due to the vastness and variety of involved parameters. This may be achieved by the development of mathematical models and also optimization of the process parameters to control and obtain the required weld bead geometry. Investigation into the relationship between the welding parameters and the bead geometry began in the mid -1900s.

Lee and Um reported some of the first works in which regression analysis was applied to welding geometry research [1]. In last decade, several trials were made by various researchers to analyze different welding processes using of regression method.

Kim et al., used regression analysis for modeling the Gas Metal Arc Welding (GMAW) process and discussed the effects of process variables on the weld bead-geometric parameters [2]. Ganjigatti et al., established input-output relationships in Metal Inert Gas (MIG) welding process through regression analysis [3]. Xue et al., applied fuzzy regression method for proper prediction of process variables in the robotic arc-welding process [4]. Most of the work reported on the optimization of weld bead geometry is directed to Genetic Algorithm (GA).

Vasudevan et al., 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 [5]. In another work, Nagesh and Datta applied Genetic Algorithm for optimization of welding parameters to achieve desired height to width ratio in TIG welding process [6]. A binary-coded Genetic Algorithm was used by Dey et al., to optimize bead geometry in Electron Beam Welding (EBW) process [7].

In 2007, Atashpaz-Gargari and Lucas introduced the basic idea of Imperialist Competitive Algorithm (ICA) to solve the real world engineering and optimization problems [8]. 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 problems in recent years, some of those are mentioned below. In Atashpaz-Gargari et al., 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 [9].

Biabangard-Oskouyi et al., employed ICA for reverse analysis of an artificial neural network in order to characterize the properties of materials from sharp indentation test [10]. Nazari et al., solved the integrated product mix-outsourcing (which is a major problem in manufacturing enterprise) using ICA [11]. Kaveh and Talatahari utilized the ICA to optimize design of skeletal structures [12]. Yousefi et al., presented the application of Imperialist Competitive Algorithm for optimization of cross-flow plate fin heat exchanger and 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 [13].

Mozafari et al., applied ICA to optimize intermediate epoxy adhesive layer which is bonded between two dissimilar strips of material [14]. 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.

Towsyfyan et al., have published several works to compare the effectiveness of ICA compared with other evolutionary algorithms [15-18]. From the literature review carried out in present study it has been found that in most cases, the cost function going to be optimized has a complicated nature which confirms the ability of ICA in dealing with difficult optimization tasks.

In this paper, the basic idea of Imperialist Competitive Algorithm (ICA) is introduced and two case studies from literature are presented to show the effectiveness of the proposed algorithm. In this regard, the weld bead area in Electron Beam Welding (EBW) and Submerged Arc Welding (SAW) processes is mathematically modelled and optimized using of ICA. To benchmark the proposed approach, comparison is made against GA method.

Genetic Algorithm is a population-based search and evolutionary algorithm method. This algorithm is inspired by the natural biological evolutionary process comprising of selection, crossover, mutation, etc. The evolution starts with a population of randomly generated individuals in first generation and terminates, when either a maximum number of generations has been produced or a satisfactory fitness level has been reached for the population. Interested readers may refer to works of Deb, for a detailed discussion on the principle of the GA [19], [20].

2 BASIC IDEA OF IMPERIALIST COMPETITIVE ALGORITHM (ICA)

With reference to the work of Winiczeko, generally speaking, optimization algorithm is a kind of computer simulation of processes observed in the nature, but ICA presents different points of view [21]. It is algorithm motivated by the socio-politically mechanism. In this case, solutions of optimization problem are called countries. Each country can play a role of colony or imperialist. The power of a country is represented by the value of cost function defined by the programmer. The strongest countries become imperialists and the others are considered as their colonies. Both of imperialist and its colonies create the empire. Total power of the empire is dependent on power of imperialist and all its colonies. It can be calculated by the following equation:

$$T_n = C_n + \xi c_n \qquad (1)$$

Where T_n is the total cost of the nth empire; C_n is the cost of the nth imperialist; c_n is the mean cost of all colony of the nth empire; ξ is a number from range (0,1).

The essential of the ICA is competition of the empires. As a result of this competition, the weakest empires collapse and the most powerful ones take possession of their colonies. Another result of competition is changing position of countries by means of moving colonies toward their imperialist, changing coordinates of imperialist and eliminating the powerless empires [21]. The working of algorithm is presented by the flowchart shown in Fig. 1.

3 PROBLEM STATEMENT AND MATHEMATICAL FORMULATION

Complexities of welding variables on the one hand and its widespread use in producing the sensitive and expensive parts on the other hand have doubled the importance of precise control of its adjusting parameters. Among a wide variety of welding processes, Electron Beam Welding (EBW) and Submerged Arc Welding (SAW) process have been considered in this study. In general, in order to create high-quality joints in welding processes it is necessary to control three parameters of welding current (I), voltage (V) and welding speed (S) precisely from various variables. On this basis, the mentioned variables have been considered as the adjusting parameters. It is well known that in welding process, weld bead geometry and weld quality are, in most parts, depending on adjusting parameters so that the weld quality is usually measured in terms of weld bead geometry which that includes Bead Height (BH), width (BW) and penetration (BP).

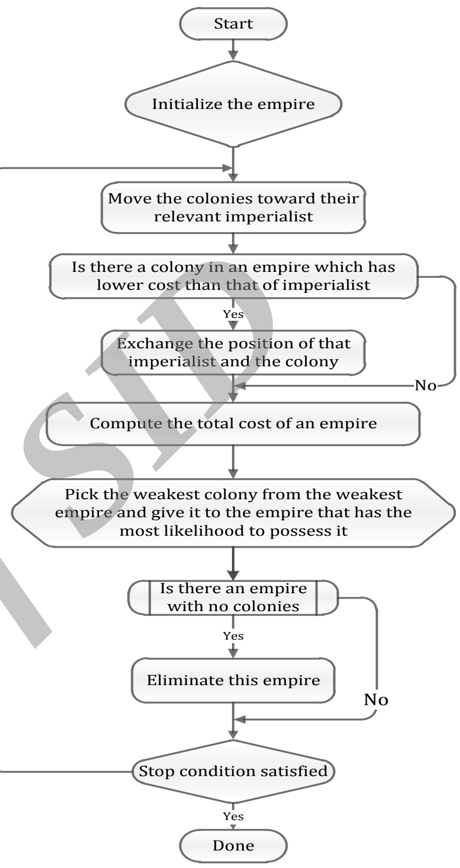


Fig. 1 Flowchart of the Imperialist Competitive Algorithm

The aim of present study was to determine the set of optimal parameters of welding process to ensure minimum weld area in SAW and EBW processes. According to Fig. 2, the weld area may be obtained in terms of bead height, width and penetration.

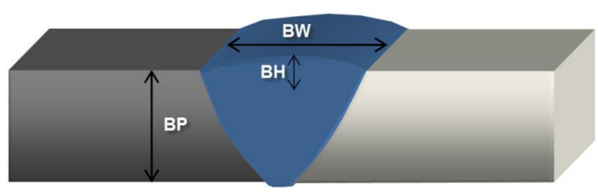


Fig. 2 Schematic illustration of weld geometry

Based on the assumption that the weld area follows the parabolic curves, the above considered optimization problem can be mathematically stated as follows [7].

Minimize: *Weld area* = 2/3 [(*BH*+*BP*) *BW*] (2)

Based on the regression analysis carried out by Dey et al., weld bead geometry parameters (BH, BP and BW) in terms of process variables (I, V, S) in electron beam welding processes can be considered as follow [7]:

$$BH = 0.2691 - 0.0162V + 0.1033I + 0.0008S + 0.0002V^2 + 0.0012I^2 + 0.00002S^2 - 0.0006VI - 0.00006VS - 0.0004IS \quad (3)$$

$$BW = 6.6778 + 0.0103V - 0.8200I - 0.0437S - 0.00019V^2 + 0.0539I^2 + 0.0004S^2 + 0.0027VI - 0.00007VS - 0.0023IS \quad (4)$$

$$BP = -11.2643 - 0.3047V + 4.9734I + 0.0697S + 0.0028V^2 - 0.220I^2 - 0.0004S^2 - 0.0089VI - 0.00006VS - 0.0021IS \quad (5)$$

According to the work of Karaoglu and Secgin [22], the mathematical model of weld bead parameters in submerged arc welding processes based on regression analysis can be considered as follow.

$$BH= (1.4978 * (I^{0.6464} / V^{0.7788} * S^{0.4882})) \quad (6)$$

$$BP= (0.000235 * (I^{1.7628} / V^{0.4114} * S^{0.0838})) \quad (7)$$

$$BW= (0.0549 * (I^{0.6005} / V^{0.8174} * S^{0.4728})) \quad (8)$$

Substituting Eqs. (3, 4, 5) in Eq. (2) we achieve weld area function in EBW process:

$$\text{Weld area} = 2/3[(-10.9952 - 0.3209V + 5.0767I + 0.0705S + 0.003V^2 - 0.2189I^2 - 0.00038S^2 - 0.0095VI - 0.00012VS - 0.0025\ I\ S) * (6.6778 + 0.0103V - 0.8200I - 0.0437S - 0.00019V^2 + 0.0539I^2 + 0.0004S + 0.0027V - 0.00007VS - 0.0023IS)]. \quad (9)$$

Substituting Eqs. (6, 7 and 8) in Eq. (2) we get weld area function in SAW process.

$$\text{Weld area} = 2/3\{[(1.4978 * (I^{0.6464} / V^{0.7788} * S^{0.4882})) + (0.000235 * (I^{1.7628} / V^{0.4114} * S^{0.0838}))] * (0.0549 * (I^{0.6005} / V^{0.8174} * S^{0.4728}))\} \quad (10)$$

Eqs. (9 and 10) are cost functions that aim to be minimized in this study.

4 RESULTS AND DISCUSSION

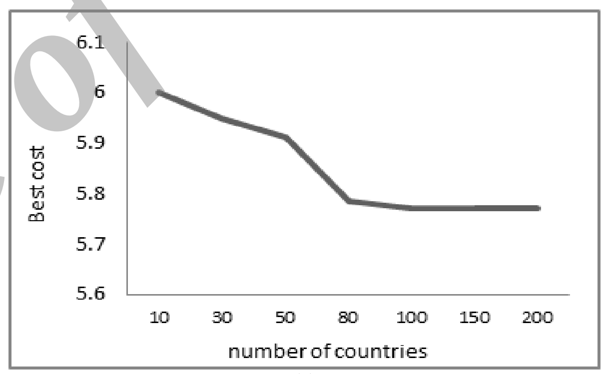
4.1. Minimum weld bead geometry area (cost function)

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. After very careful investigation, ICA parameters were selected based on Table 1.

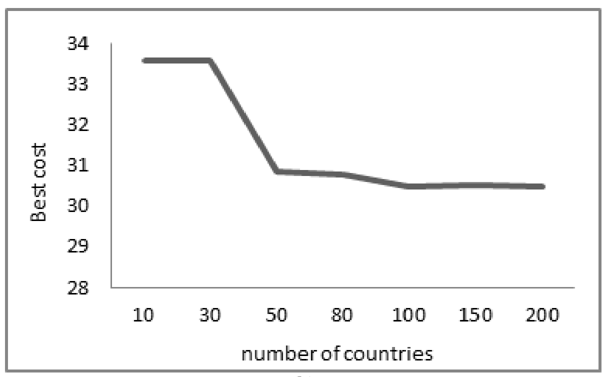
Table 1 Selected ICA parameters

ICA Parameters	EBW	SAW
Revolution rate	0. 3	0.2
Number of Countries	100	100
Number Of Initial	5	5
Imperialists	100	100
Number of decades	0.5	0.5
Assimilation Coefficient (β)	0.5	0.5
Assimilation Angle	0.02	0.02
Coefficient (γ)	(60, 9,70)	(480, 26,
Zeta ζ	(90, 10,	17.40)
Variable min (I, V, S)	80)	(720, 37,
Variable max (I, V, S)		19.70)

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 can be seen in Fig. 3. 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.



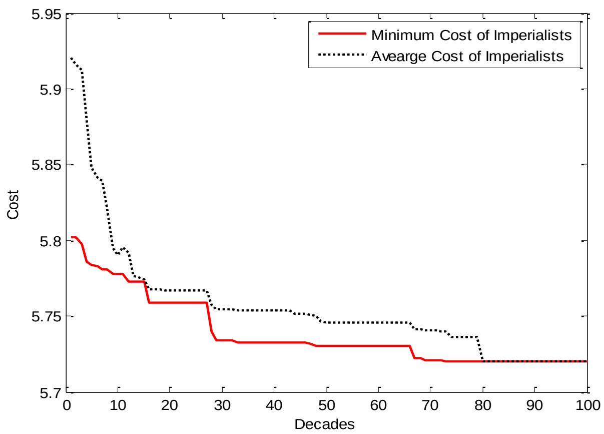
(a)



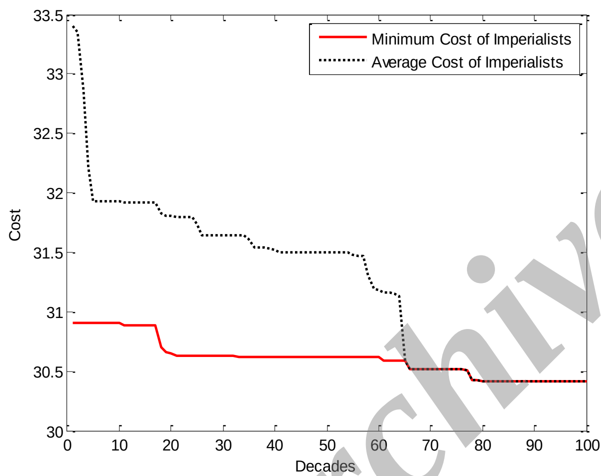
(b)

Fig. 3 Effect of variation of the number of countries on the minimum weld area: (a) EBW, (b): SAW

According to Fig. 3, it can be seen that in both case studies the variation of the objective function is considerable for the number of countries less than 100. Increasing the number of countries up to 100 slightly improves the results. Although more increase in the number of initial countries yields in decrease in the objective function, the changes is not considerable. Therefore, the number of countries for this study is set to 100 for the rest of the paper.



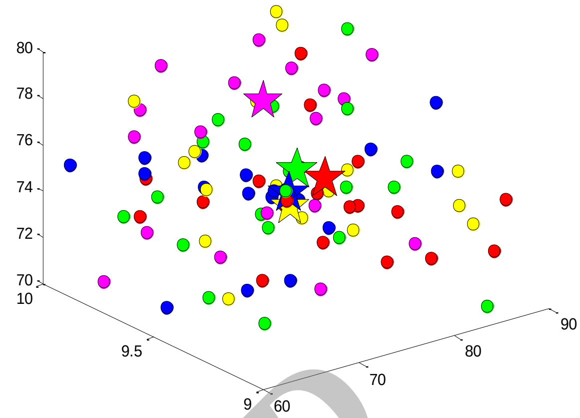
(a)



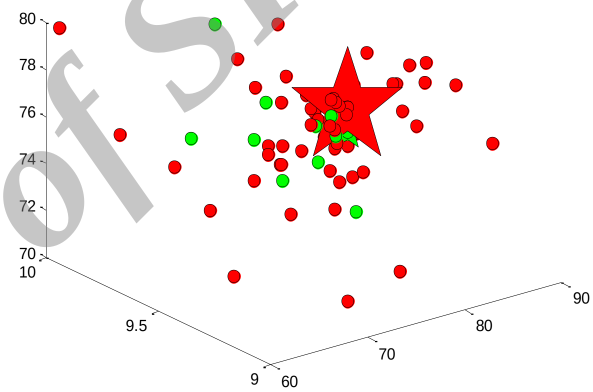
(b)

Fig. 4 Convergence of the objective of minimum weld area, (a): EBW, (b): SAW

Fig. 4 demonstrates the iteration process of ICA method for EBW and SAW process. A significant decrease in the target function is seen in the beginning of the evolution process. After certain decades, the changes in the fitness function become relatively minute. The minimum area of the weld after 100 decades was found to be 5.72765 mm^2 and 30.49291 mm^2 for EBW and SAW process respectively.
In both optimization processes, initial number of countries is 100 which 5 of the best ones are chosen to be the imperialists and control others. Figs. 5 and 6 illustrate the initial empires, empires at iterations 50 and 100 (convergence), for EBW and SAW process respectively.



(a)



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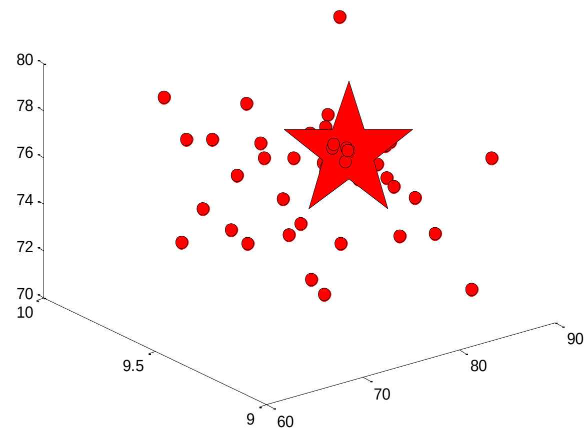
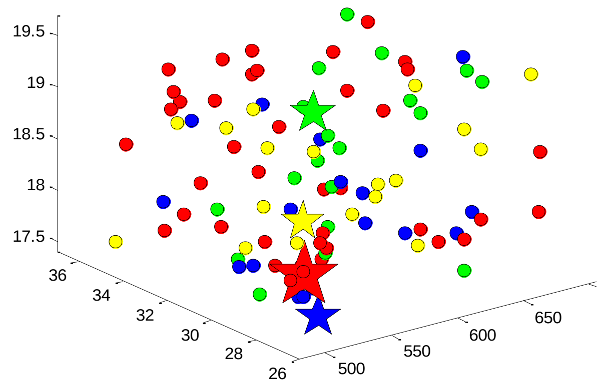
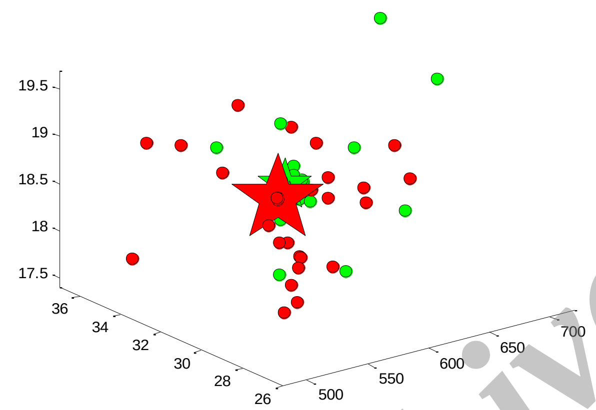


(c)

Fig. 5 Empires in optimization of EBW (a): Initial empires, (b): Empires at iteration 50, (C): Final solution.



(a)



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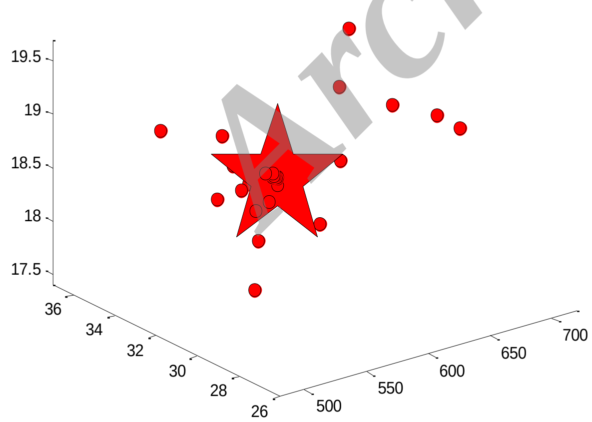

(c)

Fig. 6 Empires in optimization of SAW (a): Initial empires, (b): Empires at iteration 50, (C): Final solution

4.2. A Comparison between ICA and GA

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 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 table 1 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 terms of accuracy and computational time. The results are demonstrated in Table 2 and 3, where it can be concluded that the results are completely comparable in comparison with the work of Dey et al., and Karaoglu and Secgin for optimizing EBW and SAW process [7], [22].

Table 2 Comparison of results from ICA and GA method for EBW process

Optimization methods					
	ICA	GA		ICA	GA
Acceleratin g voltage (KV)	68.55 15	68.4 411	Beam current (mA)	9.02 95	9.0 35
Welding speed (Cm/min)	79.28 23	79.5 979	CPU time (s)	8	13
Bead width (mm)	2.175 94	2.17 411	Bead height (mm)	0.33 48	0.3 33
Bead penetration (mm)	3.644 24	3.63 806	Minimum area of weld(mm^2)	5.72 76	5.7 41

Table 3 Comparison of results from ICA and GA method for SAW process

Optimization methods					
	ICA	GA		ICA	GA
Acceleratin g voltage (KV)	26.32 56	26.3 9909	current (A)	482. 3936	481 .99 67
Welding speed (Cm/min)	19.53 85	19.4 0257	CPU time (s)	8	13
Bead width (mm)	7.970 97	8.01 169	Bead height (mm)	1.49 14	1.4 935
Bead penetration (mm)	4.277 62	4.27 877	Minimum area of weld(mm^2)	30.4 9291	3.9 369 6

Since the minimum weld area is desired, the optimal weld area values in Figs. 7 and 8 are compared for

EBW and SAW respectively. As it is illustrated in these figures, ICA is more successful for predicting the minimum weld area in less computation time.

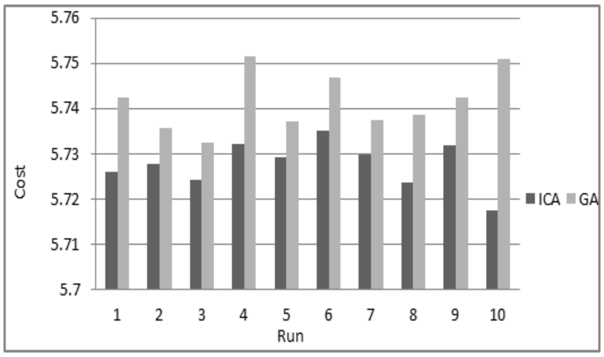

Fig. 8 Optimization results for the weld area in EBW process

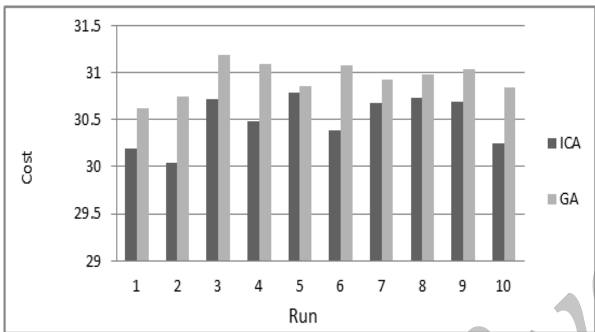

Fig. 9 Optimization results for the weld area in SAW process

5 CONCLUSION

In this study, an optimization problem was formulated to minimize weld area in SAW and EBW process. In this regard**,** three parameters including the current, speed and welding voltage were selected as the input variables and the weld bead penetration, width and height were modelled. Thus, Minimum weld area was considered as single objective function and imperialist competitive algorithm was used for optimization of welding process. The performance of the above approach has been compared to Genetic algorithm. According to the results, ICA algorithm comparing to the traditional GA shows considerable improvements in finding the optimum process parameters in less computational time under the same population size and iterations. Simplicity, accuracy, and time saving are some of advantages of the ICA algorithm. Moreover, considering the high complexity of the cost function going to be minimized, this confirms the ability of ICA in dealing with difficult optimization tasks. The proposed approach may be employed easily in automated or robotic welding process in the form of a program, for obtaining the optimum weld bead dimensions and optimization of different welding process based in the desired objectives.

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