A V-Groove CO_2 Gas Metal Arc Welding Process with Root Face Height Using Genetic Algorithm

S. Ahn and S. Rhee

Abstract

A genetic algorithm was applied to an arc welding process to determine near optimal settings of welding process parameters which produce good weld quality. This method searches for optimal settings of welding parameters through systematic experiments without a model between input and output variables. It has an advantage of being able to find optimal conditions with a fewer number of experiments than conventional full factorial design. A genetic algorithm was applied to optimization of weld bead geometry. In the optimization problem, the input variables were wire feed rate, welding voltage, and welding speed, root opening and the output variables were bead height, bead width, penetration and back bead width. The number of level for each input variable is 8, 16, 8 and 3, respectively. Therefore, according to the conventional full factorial design, in order to find the optimal welding conditions, 3,072 experiments must be performed. The genetic algorithm, however, found the near optimal welding conditions from less than 48 experiments.

Key Words : Arc welding, Genetic algorithm, Optimization, Welding process parameter, Welding speed, Welding voltage, Weld bead Geometry, Wire feed rate.

1. Introduction

Recently, multi-pass welding is preferred than single-pass welding in manufacturing process for economic and effective welding process in industrial site. Butt welding is the most representative welding type in performing single-pass welding. Among butt welding, I-shape welding requires convenient work, but imperfect welding is highly likely if it is thick (Ex: over 6 mm). V-Groove type is effective for thick butt welding process. The welding process cost and time considerably depend on root face height among other conditions. Accordingly, it is required to evaluate proper root face height to obtain the effect of reducing cost and shortening time during welding process, and study on optimized welding process conditions is very important.

In the mean time, since CO_2 Gas Metal Arc Welding Process is multiple input output process where welding output variables are complicatedly connected, welding process variables are obtained after trial and error from many experiments and efforts to get good welding quality. It is important to normalize the model between input variable and output variable of welding process and to determine welding process variable from this. In general, welding process model has been derived using theoretical analysis or numerical analysis method [1~3]. However, these models do not consider non-linearity of welding process since they are based on lots of assumptions. On the other hand, a method was suggested that derives the welding

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process model using experiment data as a way to complement this. For example, some model derives the linear model between welding bead form variable and welding process variable using the regression analysis [4,5], or some study derives nonlinear model using artificial neural network [6~8]. However, these models produce exact value in the areas of given experiment due to non-linearity and complexity of welding process, but less exact values in the areas of expanded experiment. In addition, these models show burn-through in the investigation area of welding process variables and the bead form from this fail to give exact information required to derive model. Accordingly, it is required to find the areas showing relatively fair welding quality as a precedent work, and depends on the experiment based on experience to identify such area of interest. However, it takes lots of experiment and experience to find the area of interest through this experience-oriented experiment, and it is difficult to apply this in new welding process.

This study aims to find the optimal welding variable from a few systematic experiments rather than deriving the model between input variable and output variable of welding process in order to obtain good quality. And for the welding process conditions, optimal welding process variable according to height of roof face with considerable economic effects will be obtained using generic algorithm.

2. Generic algorithm for welding process optimization

Generic algorithm is the complete optimal algorithm based on natural selection and hereditism. In addition, since this algorithm is complete algorithm and does not require object function for optimization to be differentiated, it has an advantage of resolving the optimization problem of object function with multiple polarity or un-continuous object function which are difficult to apply optimization algorithm based on existing gradient.[9,10] In this regard, this study used generic algorithm to determine the optimal welding process variable in order to obtain the desired welding bead form. Generic algorithm has the features as shown below [9].

Fig. 1 is the flow chart for general optimization process that uses generic algorithm. Initial population means the possible solution group for optimization problem and each solution is called individual. Individual is the binary string coded with the combination of 0 and 1 randomly generated in general. This binary string codes the possible solution and means the welding process variable that affects the welding bead form in this thesis. Welding process variable value expressed in binary string is effective for exchanging generic information between individual, but should be converted to the real value in order to apply to the optimization problem and to evaluate the level of appropriateness. While general optimization algorithm performs investigation based on one starting point, generic algorithm starts investigation after generating the individual group of certain size with possible solutions for optimization problem.

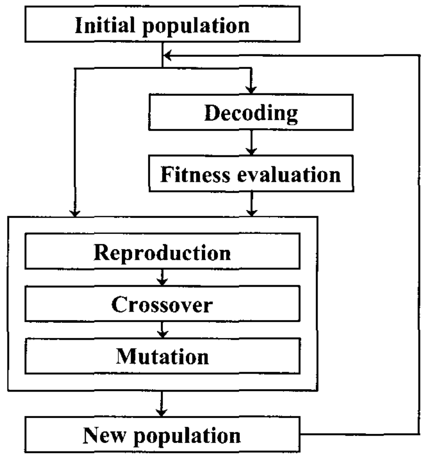


Fig. 1 General procedure of a genetic algorithm

Since the size of solution group is one of important factors that affect the optimization performance of generic algorithm and this study requires more experiment if the number of individual is more, this study reduces the number of individual as few as possible.

Decoding is the procedure of converting the input variable coded in binary string to the real value. For example, if process variable x_i is expressed as binary string with the investigation area $[x_{i,\min}, x_{i,\max}]$ and the length of string L_i, real number value $x_{i,r}$ of welding process variable x_i can be calculated in the following formula.

$$x_{i,r} = \frac{x_{i,\max} - x_{i,\min}}{2^{L_i} - 1} x_{i,b} + x_{i,\min} \qquad (1)$$

Here $x_{i,b}$ is the value converting the binary string to decimal. Individual expressed in binary string according to Eq. (1) is converted into real number value and applied in optimization problem. That is, welding experiment is performed for each welding process variable converted to the real number value.

Fitness evaluation is used to determine the existence of individual in generic algorithm. Since the individual with higher fitness for each question means better solution, fitness function means the object function that the user wants to maximize. In this study, fitness function was prepared using the bead height, bead width of welding bead form, penetration depth and back bead width. Fitness was calculated for each welding condition by measuring the welding bead shape obtained after performing welding experiment.

Next stage is the process for making the population of next generation using the information exchange between individuals in binary string and the fitness of individual. This population is determined using generic operators such as reproduction, crossover, and mutation.

Reproduction is the process that individual is reproduced according to its fitness. This operation process explains the Darwin's survival of the fittest that the individual with higher fitness produces more artificial descendent in the next generation than the individual with lower fitness, and that the individual that well adapts to the given environment survives. This thesis used roulette wheel choice method as the method to implement this.[9]

When the fitness value of individual i consisting of n individuals is f_i, the sum of fitness of all individuals $\sum_{i=1}^{n} f_i$, and average fitness value is $\bar{f}$, the possibility of individual i being selected is $f_i / \sum_{i=1}^{n} f_i$, and individual i will reproduce the $f_i / \bar{f}$ individuals on the average. Accordingly, the individual with fitness over the average one is highly likely to reproduce over 1 child, and the individual with fitness less than average is highly likely not to reproduce the child. However, there exists a possibility of choice as much as $f_i / \sum_{i=1}^{n} f_i$ from the individual with low fitness. This choice method prevents the rapid decline in diversity of population, it can avoid premature convergence before finding good solution. The individual selected by this method will be saved in the mating pool.

Cross is the operator of producing the children while the creature in the nature system exchanges gene and is proceeded in 3 stages. First, select 2 strings randomly from the mating pool. Second, select the cross location randomly. Third, exchange some strings based on the cross location. New individual is created as the information between individuals is combined in this process. This cross is not made for all strings, but is restricted by crossover rate.

While reproduction and cross uses information that individual has currently, mutation is the process of providing information that does not exist in the current individual group. This operation process is performed by converting some beat value among string. That is, the beat value of 0 is reversed to 1 and the beat value of 1 is to 0. This process plays a role of recovering the past information lost by the reproduction and cross, or providing information not contained in initial population. This operation process is also restricted by mutation rate.

Number of individual, cross rate and mutation rate in generic algorithm are important factors in performance of algorithm[10,11]. In particular, it is required to restrict the number of individual as few as possible in order to find the optimal conditions through actual experiment, rather than computer simulation, using generic algorithm. That is, the number of experiment increased as the number of individual increases, which results in increasing the cost and time for experiment, and reducing the efficiency of optimization by generic algorithm. This study sets the control parameter of generic algorithm based on the study of Reeves [11] in order to obtain good results in as few individual as possible in order to reduce the number of experiment.

3. Experimental method

Fig. 2 is the map of welding bead form that affects the mechanical features of welding part. As shown in the figure, the geometrical form of welding bead is expressed as height H, bead width W and penetration depth P and back bead width B. These bead form variables are affected much by the setting of welding process variables, which used wire speed, welding velocity, welding speed and root opening. Therefore, welding process variable and bead form variable can be regarded as input variable and output variable of arc welding process, respectively. This study set the desired welding bead form and used generic algorithm to determine the welding process variable affecting it.

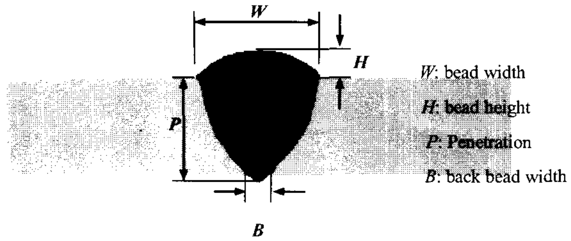


Fig. 2 Weld bead geometry

Basic material to be welded is the soft steel in 8.8mm thick, and the joint is V- groove type. In addition, welder with constant voltage feature of inverter type was used for welding power. Pole wire is AWS ER 70S-6 solid wire and pole diameter is 1.2 mm. The distance from contact tube to basic material (contact tube - to - work distance) was set to 20mm. Shielding gas used for this experiment is 100% CO_2 gas and gas flow is 20 *l*/min.

General optimization algorithm requires lots of experiment with the bigger investigation scope and higher resolution. Effective investigation can be done when the scope of process variable is determined in the way that its optimization point is included in the scope. The resolution needs to be higher if the variable has bigger effect in the output. However, it has weakness that the effects of other variables cannot be observed if we set the bigger investigation area and resolution for only one variable. Accordingly, since the input variable, scope of each welding process variable should be determined in consideration of effects and resolution for welding bead form, the output value, the scope of welding process variable was based on literature for arc welding conditions[12)] and several precedent experiments. Following are the conditions for this. Investigation scope of wire speed is 60 ~ 105 mm/s, investigation scope of welding voltage, 17 ~ 38 V, investigation scope of welding speed, 3 ~ 10 mm/s and root opening, 0~2mm. Experiment was performed with root face height of 3mm. After performing welding for the input condition set by generic algorithm, output values such as bead height, bead width, penetration depth and back bead width were measured.

4. Results and examination of experiment

The index for evaluating the existence in the next generation is required to optimize the welding process variable using generic algorithm. This study aims to get the welding part of the complete welding status[13)], and made object function as shown in Eq. (2) using the bead height, bead width, penetration depth, back bead width and welding speed as shown in the Fig. 3 as the geometrical form variables of welding bead that affect the quality of welding part.

$$J = \hat{I}(W) + \hat{I}(H) + \hat{I}(P) + \hat{I}(B) + \hat{I}(S) \quad (2)$$

Here, are the bead width, bead height, penetration depth, back bead width and welding speed obtained from experiment, respectively. This study performed tensile strength[14)] and bending strength test [15)] according to welding quality of some welding conditions in order to check the validity of object function as a reference. Only form factors of affecting the tensile strength are used in J value. Fig. 4 shows the tensile strength and bending strength of welding part according to the form of basic materials according to some welding quality. For your reference, tensile strength and bending strength of basic material part are 350 MPa and 765Mpa, respectively. In Fig. 4(a), it has

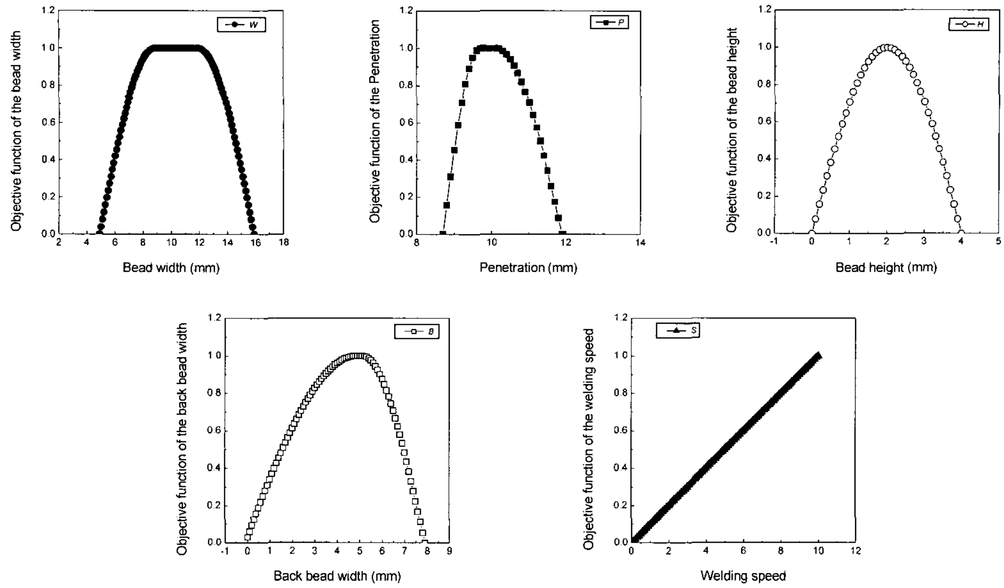
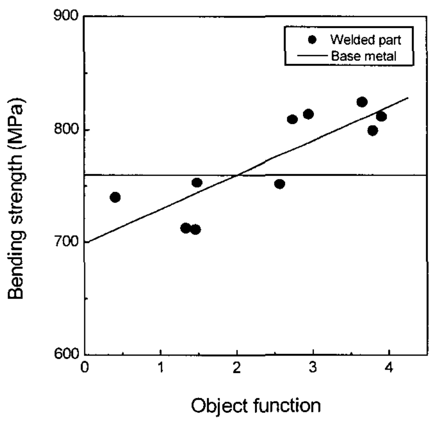


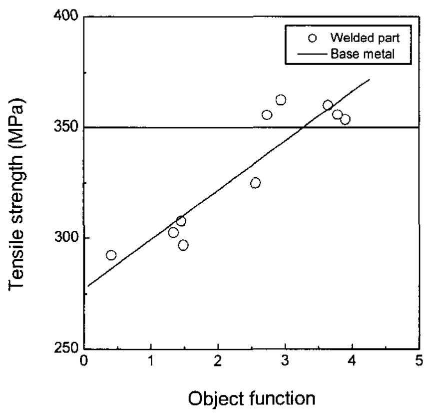
Fig. 3 Object function with geometric condition of the welded part

welding part in perfect penetration status if object function value J of Eq. (2) is over 3, and the tensile strength and bending strength are found to be higher in welding part than in basic material part. In addition, the strength increases as this J value increases and this tendency was found to be similar in tensile strength. Accordingly, obtaining the optimal bead form in the optimization problem means finding the welding process variable that makes of Eq. (2) as maximum.

Investigation scope, number of beats and number of levels of process variable for finding the welding process variable that makes Eq. (2) as maximum are summarized in Table 1. Accordingly, since the number of investigation points for finding optimal process variable by factor experiment with same number of levels as Table 1 is 3,072 and it requires too many experiments to apply this method, it is unrealistic. Following is the process of determining the optimal welding process variable using the generic algorithm



(a) Bending strength



(b) Tensile strength

Fig. 4 Bending strength and tensile strength of the welded part under the arbitrary welding condition that can search complete optimization point while reducing the experiment as much as possible from this extensive investigation area.

Table 1 Search range for welding parameters, and the corresponding number of bits and number of levels

Parameter	Range	Number of bits	Number of leves
Wire feed rate	60 ~ 105 (mm/sec)	4	16
Welding Voltage	17 ~ 38 (V)	3	8
Welding speed	3 ~ 10 (mm/sec)	3	8
Root opening	0 ~ 2 (mm)	2	3

First, initialize the control parameters of generic algorithm. This study sets the number of individual to 8, cross rate to 0.95, mutation rate to 0.01. Then, generate the as many binary strings as the number of individual. In general, initial binary string is generated randomly, and the Table 2 is the initial string. Each line means the individual consisting of 3 welding variables; 1^{st} to 3^{rd} row mean welding voltage; 4^{th} to 7^{th} row mean wire feed rate; and 8^{th} to 10^{th} row mean welding speed, 11^{th} to 12^{th} row means binary number corresponding to root opening. Then, convert the binary string for each welding individual set by orthogonal array to the value in the scope of Table 1 using the Eq. (1). And perform arc welding experiment using each welding process variable value converted. After measuring the welding bead form obtained from each condition of experiment, calculate the object function value by Eq. (2) and calculate the fitness function value using such value. Table 3 shows the experiment results for each condition and welding process variable values of 1^{st} generation generated by orthogonal array.

In Table 3, no. 3 is not welded due to unstable condition, and the reason why penetration is almost not performed in the welding condition of experiment no. 4 and 6 is relatively small welding voltage in the given wire feed rate, resulting in very unstable arc and formation of non-uniform welding bead. This result can be checked in Fig. 5.

4 individuals were selected by roulette wheel choice method using the fitness value calculated for each individual. The population of 2^{nd} generation was determined after crossing the individual selected as much as cross rate and mutating each individual by mutation operator. Repeat this process until satisfactory welding quality can be obtained. This study performed experiment up to 6 generation. The reason why this study performed experiment only up to 6 generation is because approximate optimization conditions showing satisfactory welding bead form was obtained in the 6^{th} generation. The identification of approximate optimization condition in the 6th generation is the result obtained from 48 times of experiment. Table 4 shows the results of experiment and welding process variables generated in 6^{th} generation.

Table 2 Initial generation

Individual number	Bit Number											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	0	0	0	1	0	0	0	1	1	0	1
2	1	1	0	0	0	1	1	1	0	1	0	0
3	0	1	1	1	1	0	0	0	0	1	1	0
4	0	0	1	0	0	0	0	0	0	0	0	0
5	1	1	1	0	0	1	1	1	1	1	1	0
6	0	1	0	0	0	1	0	0	1	0	0	0
7	1	0	1	0	0	1	0	1	0	1	0	1
8	1	0	0	0	1	1	1	0	1	1	0	1

Table 3 Results of initial generation with 3mm root face height

No.	Feed rate (mm/s)	Voltage (V)	Speed (mm/s)	Root opening (mm)	Width (mm)	Height (mm)	Back bead width (mm)	Penetration (mm)	Fitness function
1	72	29	6	1	8.7	1.9	5.8	10.5	3.872
2	75	38	6	1	11.5	1.4	5.6	11.5	3.972
3	75	29	5	1	12.3	3.4	4.8	11.4	0.143
4	90	29	8	1	6.7	2.5	3.6	11.1	0.309
5	90	29	7	1	8.2	2.7	5.9	10.7	3.996
6	81	29	6	1	8.2	2	5.2	10.9	1.740
7	87	32	8	1	8.1	1.6	5.5	10.7	2.751
8	90	32	8	1	7.5	2.5	7.5	10.1	3.501

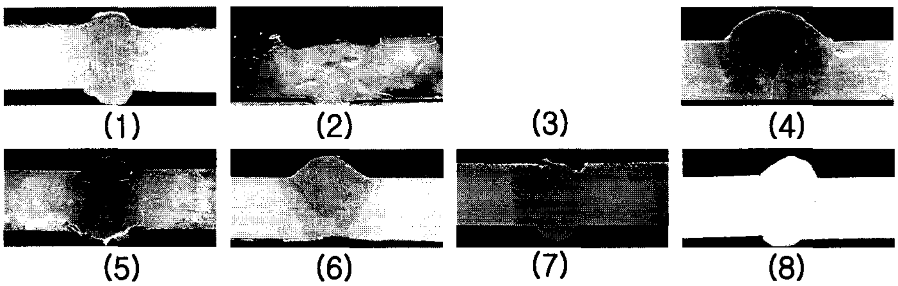


Fig. 5 Cross section of weld part in the initial generations

Table 4 Results of the sixth generation

No.	Feed rate (mm/s)	Voltage (V)	Speed (mm/s)	Root opening (mm)	Width (mm)	Height (mm)	Back bead width (mm)	Penetration (mm)	Fitness function
1	72	29	6	1	8.7	1.9	5.8	10.5	4.328
2	75	38	6	1	11.5	1.4	5.6	11.5	3.717
3	75	29	5	1	12.3	3.4	4.8	11.4	3.231
4	90	29	8	1	6.7	2.5	3.6	11.1	3.869
5	90	29	7	1	8.2	2.7	5.9	10.7	4.205
6	81	29	6	1	8.2	2	5.2	10.9	4.199
7	87	32	8	1	8.1	1.6	5.5	10.7	4.469
8	90	32	8	1	7.5	2.5	7.5	10.1	4.508

Fig. 6 shows the photo of sectional form welded at the 6^{th} generation. In the 6^{th} generation, all individuals were found to be perfectly penetrated.

Fig. 7 shows the result of optimized object function of generic algorithm performed up to 6^{th} generation. The object function value increases as the number of generation increases. In addition, the satisfactory optimal object function value was found in the 6^{th} generation.

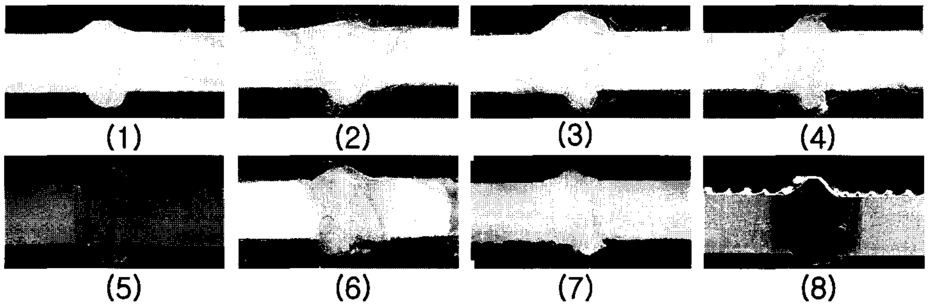


Fig. 6 Cross section of weld part in the sixth generations

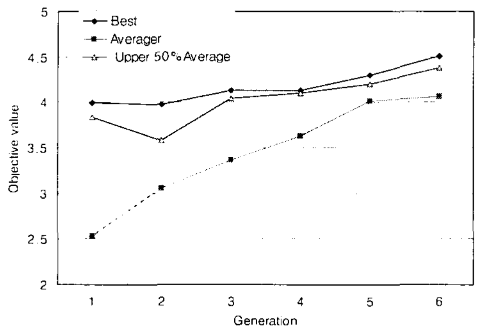


Fig. 7 Object function in each generation using genetic algorithm

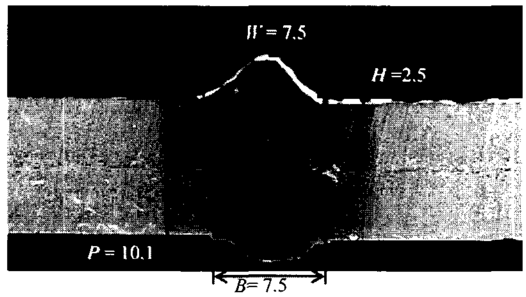


Fig. 8 Photo of the V- groove CO_2 gas metal arc welded part obtained from the optimized condition

Fig. 8 shows the photo of sectional form of V-groove welding part that has the highest object function in 6th welding process condition. Bead height is 2.56mm, bead width, 7.5mm, penetration depth, 10.1mm, back bead width is 7.5mm. Compared to the tensile strength at the welding part of Fig. 6 and basic material part, tensile strength of welding part (=362MPa) was found to be higher than basic material part (=350MPa). Accordingly, V-groove sectional welding part obtained by optimal welding process condition from generic algorithm was found to have sufficient strength.

5. Conclusion

Since arc welding process is a complicated process, it requires lots of experiment and professional knowledge for welding process to determine the welding conditions demonstrating good welding quality. In addition, precedent experiment is required to search for the areas showing relatively good welding quality for obtaining the model for welding process through experiment. This study obtained the optimal welding process conditions with welding voltage of 32V, wire feed rate of 90mm/s, welding speed of 8mm/s and root cap of 1mm from a total of 48 experiments using the generic algorithm rather than inducing the model between input variable and output variable of welding process to obtain the good CO_2 gas metal arc welding quality, and confirmed that V-groove sectional welding part obtained the optimal condition has the sufficient strength.

The method presented in this study was applied to determine the welding process condition that produces the welding part of full penetration as the designer wants. Since the welding bead form is the important factor in determining the welding quality in arc welding process, this study produced the index of evaluating the welding quality using the welding bead form variables such as bead height, bead width, penetration depth and back bead width, and set the welding process variables affecting the welding bead form as wire feed rate, welding voltage, welding speed and root opening. In optimal welding process condition, this study identified the welding process variables of full penetration form excluding the areas where burn-through occurs or penetration is almost not created in the extensive search scope for the 4 welding process variables for each case using the generic algorithm. This method evaluated the optimal conditions with much fewer experiment than the existing factor experiment method.

References

1. D. Rosenthal : Mathematical theory of heat distribution during welding and cutting, *Welding Journal*, Vol. 20, No. 5 (1946), pp. 220s-234s
2. T. W. Eager and N. S. Tsai : Temperature fields produced by traveling distributed heat sources, *Welding Journal*, Vol. 62, No. 12 (1983), pp. 347s-355s
3. W. H. Kim and S. J. Na : Numerical analysis of welding part considering the flow of melting pool and welding arc, *Korea Welding Journal*, Vol. 15, No. 1 (1997), pp. 26-35
4. P. J. Konkol and G. F. Koons : Optimization of parameters for two-wire AC-AC submerged arc welding, *Welding Journal*, Vol. 57, No. 12 (1978), pp. 367s-374s
5. L. J. Yang and R. S. Chandel : An analysis of curvilinear regression equations for modeling the submerged-arc welding process, *Journal of Material Processing Technology*, Vol. 37, (1993), pp. 601-611
6. T. K. Lim, H. S. Cho, and K. S. Bu : Control of size of melting site in GMA welding process using the neutral network, *Korea Welding Journal*, Vol. 12, No. 1 (1994), pp. 59-72
7. J. B. Lee, Y. W. Park, S. W. Oh, and H. S. Jang : A study on bead form control at GMAW, *Korea Welding Journal*, Vol. 15, No. 6 (1997), pp. 116-123
8. T. K. Meng and C. Butler : Solving multiple response optimization problems using adaptive neural networks, *The International Journal of Advanced Manufacturing Technology*, Vol. 13 (1997), pp. 666-675
9. D. E. Goldberg : Genetic algorithms in search, optimization and machine learning, *Addison-Wesley*, (1989)
10. J. J. Grefenstette : Optimization of control parameters for genetic algorithms, *IEEE Syst. Man Cybern.* Vol. 16, (1986), pp. 122-128
11. C. R. Reeves : Using genetic algorithms with small populations, *Proc. of the Fifth Intern. Conf. on Genetic Algorithms*, (1993), pp. 92-99
12. American Welding Society : Welding handbook, 8th ed.,Vol. 2, (1991)
13. ANSI/AWS D1.1-94, Structural welding code-steel, 13th Ed. , *American Welding Society*, (1994)
14. Test methods for tension testing of metallic materials, ASTM E8M-96
15. Test method for guided bend test for ductility of welds, ASTM E190-92
16. M. S. Phadke : Quality engineering using robust design, *Prentice Hall*, (1989)