Determination of Optimal Welding Parameter for an Automatic Welding in the Shipbuilding

J. Y. Park and S. H. Hwang

Abstract

Because the quantitative relationships between welding parameters and welding result are not yet known, optimal values of welding parameters for CO_2 robotic arc welding is a difficult task. Using the various artificial data processing methods may solve this difficulty. This research aims to develop an expert system for CO_2 robotic arc welding to recommend the optimal values of welding parameters. This system has three main functions. First is the recommendation of reasonable values of welding parameters. For such work, the relationships in between the welding parameters are investigated by the use of regression analysis and fuzzy system. The second is the estimation of bead shape by a neural network system. In this study the welding current, voltage, speed, weaving width, and root gap are considered as the main parameters influencing a bead shape. The neural network system uses the 3-layer back-propagation model and a generalized delta rule as learning algorithm. The last is the optimization of the parameters for the correction of undesirable weld bead. The causalities of undesirable weld bead are represented in the form of rules. The inference engine derives conclusions from these rules. The conclusions give the corrected values of the welding parameters.

This expert system was developed as a PC-based system of which can be used for the automatic or semi-automatic CO_2 fillet welding with 1.2, 1.4, and 1.6mm diameter the solid wires or flux-cored wires.

Key Words : Optimal welding parameter, Automatic welding, AI(Artificial Intelligence), Fuzzy system, Neural network, Expert system

1. Introduction

The CO_2 arc welding is a main process for an assembly stage in the shipbuilding. In these several years, special welding robots for shipbuilding were developed and widely used to increase the productivity. It is heavily important to use the optimal welding condition for the good quality and productivity. In manual welding, a skillful worker can weld adjusting the welding parameter to the optimal point during the welding. In the case of robotic arc welding, all of the welding parameters should be set to definite values such 250A, 27V, and 40cm/min, as before the welding. In order to get the values, the relationships between welding parameters and the welding results should be known. However, most of them are not yet known because the welding process contains of many unknown factors.

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Although it is a difficult task to determine the relationships between welding parameters, there are two approaches to solve the problem. The first approach is to gain an empirical equation through the regression analysis with an experimental data. The relationships between welding current vs. voltage and the current vs. melting rate were investigated in such way[1]. This method, however, reguired many welding experiments. The results obtained by this method are available only in the range that experiments are carried out. The second one is to determine the relationships of welding parameters by use of the AI (Artificial Intelligence) technique such as the knowledge base system, fuzzy system, and neural network[2]. The AI technique is an extremely useful tool for welding as it may process the non-numeric, highly complex, and uncertain information. In the research, both approaches are used. The relationships between current, voltage, and deposition rate are determined by the regression analysis with an experimental data. The weld bead shape is related to the welding parameters by the use of the fuzzy system and neural network.

Optimization of welding parameters is a correcting process of parameter values for a desirable weld bead without the defects such as the undercut, cracks, and so on. It should be known the parameters to be changed and the amount to be adjusted. Such work can be done by a knowledge-based system.

In the present research, an expert system was developed to do the above-mentioned works. The expert system contains the calculation modules, fuzzy system, neural network, and knowledge-based system.

2. Relationship in between the welding parameters and the welding result

There are many welding parameters related to the welding results, and they are dependent on each other as well. However, only a part of dependencies of them is known. In the present research, the relationships of the welding parameters were investigated by conducting the welding experiments and performing regression analysis.

It is known that the welding voltage is related to the welding current in a linear or third order polynomial. The research showed that the sigmoid functions had better consistency to experimental results as shown in Fig. 1. These Sigmoid functions are written in Equations (1) and (2). According to Lesnewich[3], melting rate is dependent on the welding current and wire extension, as shown Equation (3). Since the deposition rate is the product of the melting rate by the ace efficieney it can also be the function of the welding current as well as the wire extension therein. The regression analysis with an experimental data gives the deposition rate by using the

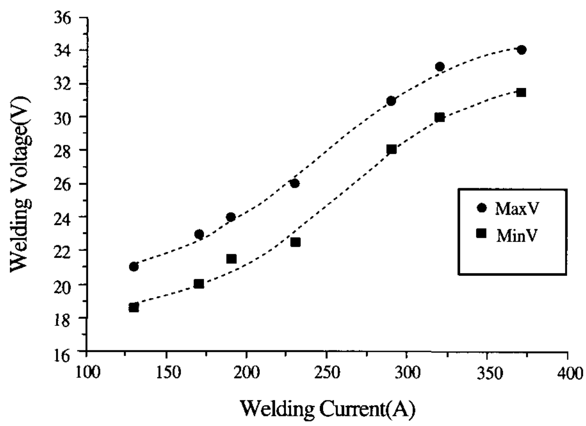


Fig. 1 The relationship in between the welding voltage and current (Flux cored wire, 1.4mm dia.)

Equation (3). Dividing Equation (3) by the current I yields Equation (4). Fig. 2 shows the relationship between welding current, wire extension and deposition rate.

$$V_{\min} = \frac{C_{11} - C_{12}}{1+e^{(I-C_{13})/C_{14}}} + C_{12} \qquad (1)$$

$$V_{\max} = \frac{C_{21} - C_{22}}{1+e^{(I-C_{23})/C_{24}}} + C_{22} \qquad (2)$$

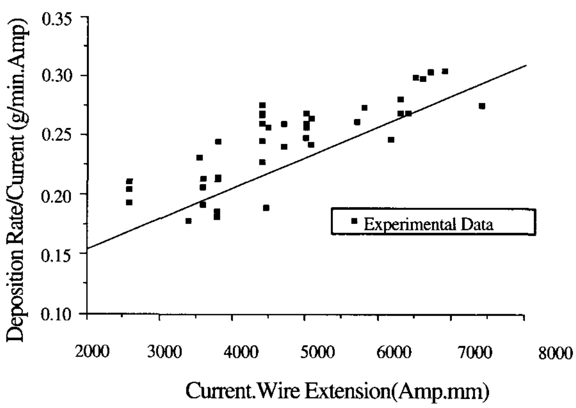


Fig. 2 The relationship between welding current, wire extension, and deposition rate (Flux cored wire, 1.4mm dia.)

$$V_D = b_1 \cdot I + b_2 \cdot I^2 \cdot l_k \qquad (3)$$

$$\frac{V_D}{I} = b_1 + b_2 \cdot I \cdot l_k \qquad (4)$$

where the lK is wire extension

Deposited area consists of three parts as shown in Fig. 3. It may be written by the Equation (5) through (8). The deposited area can also be expressed as in the Equation (9) with the welding speed V_s and deposition rate V_D. The Equation (10) and (11) are obtained from Equation (3) and (9). Welding speed Vs is determined by Equation (11).

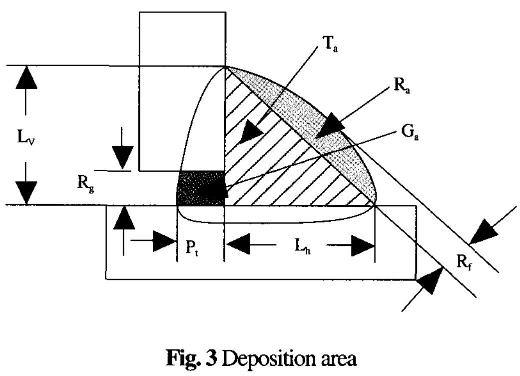


Fig. 3 Deposition area

$$A_{DEP} = T_a + R_a + G_a \qquad (5)$$

where

$$T_a = L_h \cdot L_v / 2 \quad (6)$$

$$R_a = \sqrt{L_h^2 + L_v^2} \cdot R_f \cdot 2/3 \quad (7)$$

$$G_a = P_t \cdot R_g \quad (8)$$

3. Fuzzy system

The fuzzy system has an ability to work with the uncertain information. It is a critically useful tool for solving many uncertain problems in the welding technology[4),5)]. In this research, it was used for determining the proper reinforcement area and the welding current. In general, as the leg length is larger and root gap is smaller, the reinforcement area is larger and the welding current can be higher. This empirical knowledge may be expressed in the form of rules as follows.

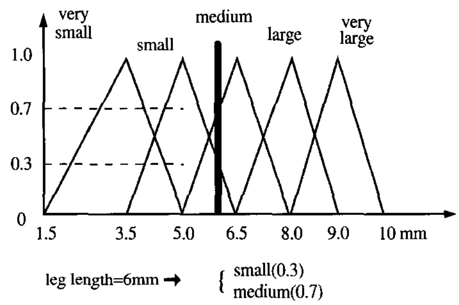
*If leg length is large and root gap is small, **Then** reinforcement area is large and applicable current is very high.*
*If leg length is medium and root gap is large, **Then** reinforcement area is small and applicable current is low.*

Although the empirical knowledge is a useful information, it cannot provide any guidance for the definite values of an optimal reinforcement area and the welding current. The fuzzy system gives the reasonably definite values of them from the above rules. Fig. 4 shows the estimating process of welding current. Fig. 4(a) is fuzzy rules that come from empirical knowledge. Fig. 4(b)-(f) show definition of fuzzy sets for leg length, root gap, and welding current, along with the approximate reasoning process for an estimation of welding current.

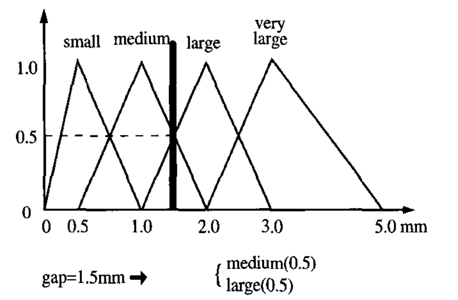
The example shows that when leg length is 6mm and root gap is 1.5mm, the welding current of 230A is recommended thereof. If the reinforcement area and the welding current are determined by the fuzzy system, welding voltage, and travel speed are obtained from Equation (9) and (11).

Rule 1. **If** leg length = very small and gap = small **then** I = low
Rule 2. **If** leg length = very small and gap = medium **then** I = low
Rule 3. **If** leg length = very small and gap = large **then** I = very low
Rule 4. **If** leg length = small and gap = small **then** I = medium
Rule 5. **If** leg length = small and gap = medium **then** I = low
Rule 6. **If** leg length = small and gap = large **then** I = very low
Rule 7. **If** leg length = medium and gap = small **then** I = high
Rule 8. **If** leg length = medium and gap = medium **then** I = medium
Rule 9. **If** leg length = medium and gap = large **then** I = low

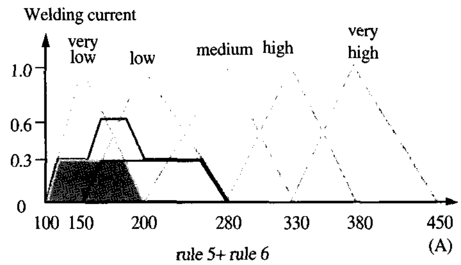
(a) Fuzzy rules



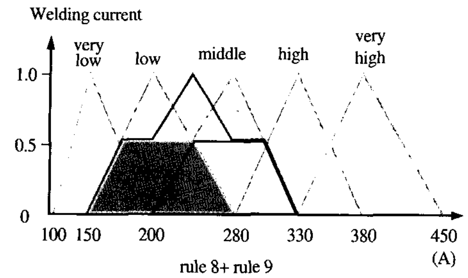
(b) Evaluation of leg length by fuzzy set



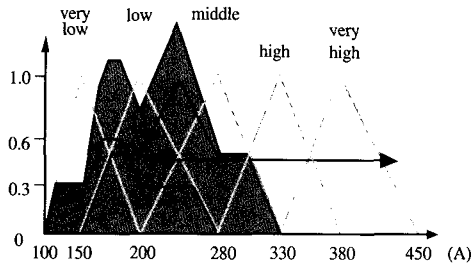
(c) Evaluation of root gap by fuzzy set



(d) Estimation of current considering rule 5 and rule 6



(e) Estimation of current considering rule 8 and rule 9



(f) Final estimation of current

Fig. 4 Estimation of welding current using fuzzy system

$$A_{DEP}=\frac{V_D \cdot 100}{V_S \cdot \rho}\ (mm^2) \tag{9}$$

$$V_D=A_{DEP} \cdot V_S \cdot \rho / 100 = b_l \cdot I + b_l \cdot I^2 \cdot l_k\ (g/\text{min}) \tag{10}$$

$$V_S=\frac{(b_l \cdot I + b_l \cdot I^2 \cdot l_k) \cdot 100}{A_{DEP} \cdot \rho}\ (cm/\text{min}) \tag{11}$$

4. Prediction of bead shape using the neural network

The weld bead shape is heavily influenced as by numerous welding parameters. In the present research, the welding current, voltage, speed, weaving width, and root gap are considered as the main parameters influencing bead shape. Fig. 5 shows their influence on the bead shape. However, these relationships cannot be expressed by a mathematical function since they contain the high complexity and many unknown factors. Artificial neural network gives a solution to this problem[6), 7)]. The complicated relationship between the welding parameters and the bead shape can be established by a self-learning function using the neural network. The neural network system in this study uses a 3-layer back propagation model and generalized delta rule as the learning algorithm. Fig 6 shows the structure of the neural network model. The input layer has five neurons that mean current, voltage, speed, weaving and root gap. The hidden layer has five neurons and the output layer has 15 neurons, which mean the 15 points on the cross section of weld bead, as shown in Fig. 7. Curve fitting was used to draw a bead profile from them. The forty data samples from welding experiments were used to train the neural network model. Bead profiles of 10 test welding were compared to the estimation by the neural network and showed a good agreement. Fig. 8 shows two examples of these comparison.

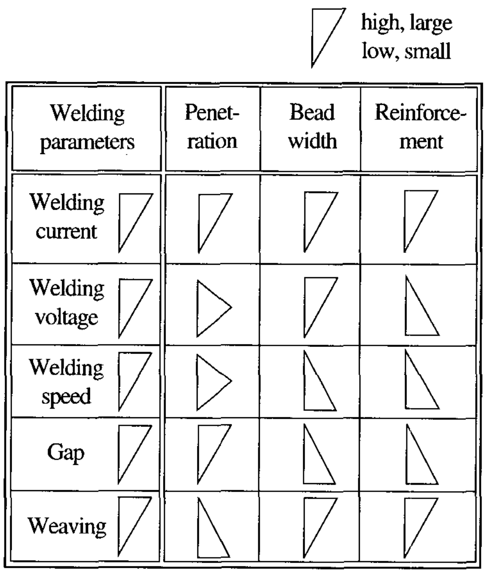


Fig. 5 Influences of welding parameters on the bead shape

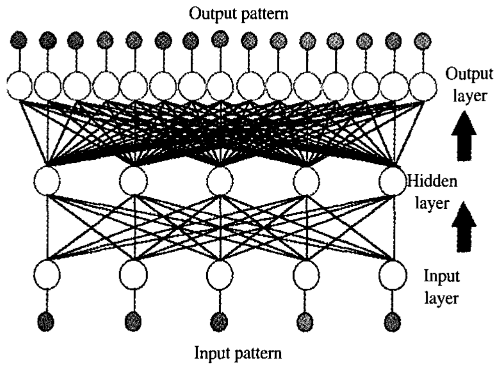


Fig. 6 Structure of neural network model for prediction of bead shape

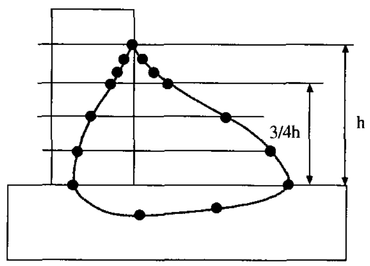
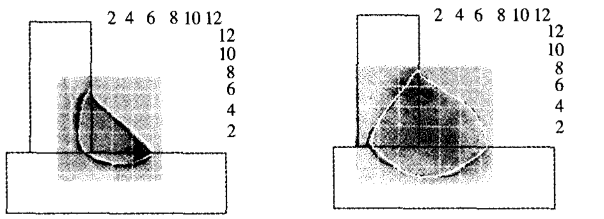


Fig. 7 Selection of 15 points to draw a bead profile



(a) Current=220A, Voltage=24.5V Speed=43cm/min Weaving(4,1),(1,4)

(b)Current=370A,Voltage=32V Speed=50cm/min Weaving(3,1),(1,3)

Fig. 8 Comparison between measured and estimated bead profile

5. Optimization using the knowledge base system

The optimization is an adjustment of the parameters for a correction of the undesirable weld bead. Undesirable bead containing weld defects results from the various causes. These causalities are represented in the form of rules. The inference engine searches the corresponding rules to the given problem and derives some conclusions from these rules[8]. These conclusions give the solutions, that is, parameters to be changed and amount to be adjusted. Fig. 9 shows the flow chart of the optimizing process. The parameter values of the undesirable bead in

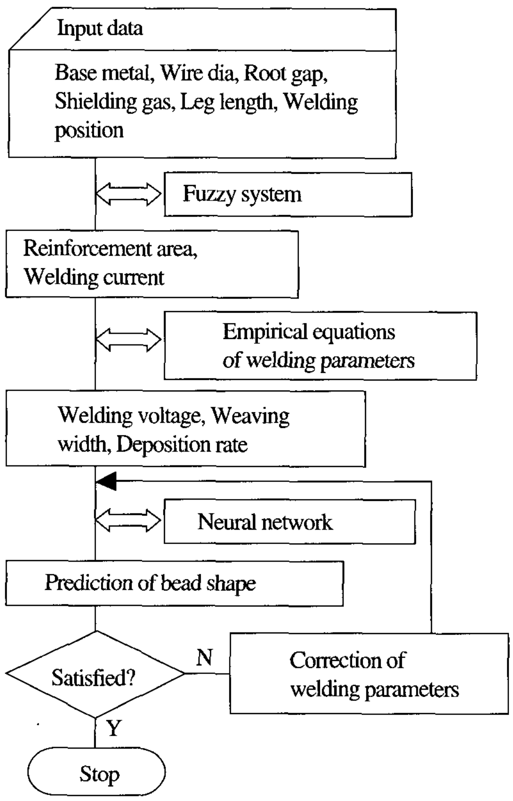


Fig. 9 Flow chart of optimization

Fig. 8(b) were optimized to 330A, 30V, and 44cm/min. The corrected bead is shown in Fig. 10.

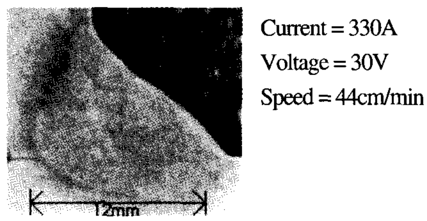


Fig. 10 Corrected bead by optimization

6. Structure of the expert system

This expert system consists of common database, fuzzy system, neural network system, knowledge base system, calculation programs and graphic user interface, as shown in Fig.10. Common database contains experimental data and coefficients of empirical functions. Calculation programs perform solving empirical equations and curve fitting to draw the bead profile.

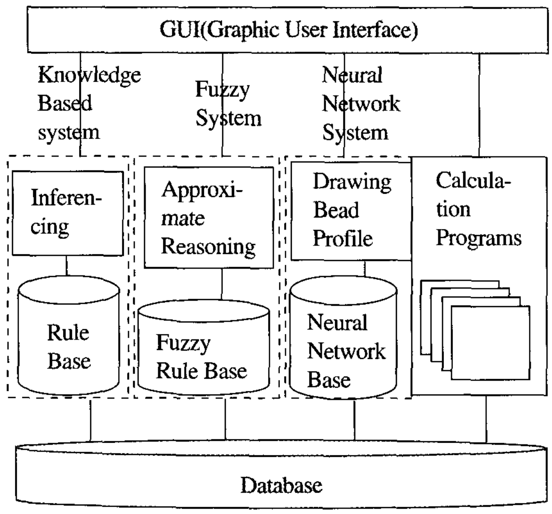


Fig. 11 Structure of expert system

7. Conclusion

CO_2 robotic arc welding requires definite values of welding parameters. However, it is very difficult because welding is a highly complex and nonlinear process. This study shows an expert system can be a solution to this difficulty. The complex relationships of welding parameters were expressed in the form of mathematical equations and fuzzy rules in the calculation programs and fuzzy system. Prediction of bead shape was carried out by the neural network system. Optimization of welding parameters was realized by the knowledge-based system. The experimental results showed the validity of the proposed expert system.

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