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Recommendation of Optimal Welding Parameter for Welding of Curved Blocks in Shipbuilding

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Abstract

Optimal values of welding parameters for CO_2 robotic arc welding is a difficult task because the quantitative relationships between welding parameters and welding result are not yet known. This difficulty may be solved by using the various artificial data processing method.

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 3 main functions. First is recommendation of reasonable values of welding parameters. For this work, the relationships between welding parameters are investigated by 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 main parameters influencing bead shape. This neural network system uses the 3-layer backpropagation model and generalized delta rule as learning algorithm. The last is the optimization of parameters for 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 welding parameters.

This expert system has been developed as PC-based system and can be used for automatic or semi-automatic CO_2 fillet welding with 1.2, 1.4 and 1.6mm size of solid wires or flux cored wires.

1. Introduction

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

Although it is a difficult task to determine the relationships of welding parameters, there are two approaches to solve this problem. The first approach is to get empirical equation through regression analysis with experimental data. The relationships between welding current and voltage, current and melting rate were investigated in this way[1]. This method, however, needs vast 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 AI(Artificial Intelligence) technique such as knowledge base system, fuzzy system and neural network[2]. The

AI technique is very useful tool for welding because it can process the non-numeric, highly complex and uncertain infor-mation. In this research both of two approaches are used. The relationships between current, voltage, deposition rate are determined by regression analysis with experimental data. Weld bead shape is related to the welding parameters by use of fuzzy system and neural network.

Optimization of welding parameters is a correcting process of parameter values for a desirable weld bead with no defect such as undercut, crack and so on. It requires which parameters and how much must be changed, that is done by a welding engineer. This work can be done by a knowledge-based system.

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

2. Relationship between welding parameters and welding result

There are many welding parameters relating to welding results and they are dependent on each other. However, only a part of dependencies of them are known. In this research, the relationships of welding parameters were investigated by welding experiments and regression analysis.

It is known that welding voltage is related to the welding current in a linear or third order polynomial. This research shows sigmoid functions has better consistency to the experimental result as shown in Fig. 1. These sigmoid functions are written by Equation 1 and 2. According to Lesnewich[3], melting rate is proportional to the square of welding current. Since deposition rate is the melting rate multiplied by the arc efficiency, it can be also the function of the welding current. Regression with experimental data gives the function for deposition rate by equation 3. Dividing equation 3 by current I, we obtain equation 4. Fig. 2 shows the relationship between welding current, wire extension and deposition rate.

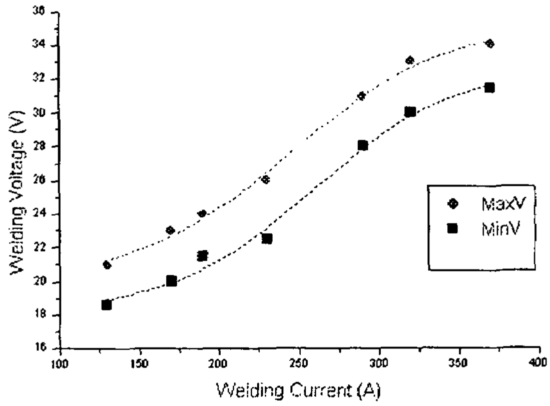


Fig. 1 Relationship between welding voltage and current (Flux cored wire, 1.4mm dia.)

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

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

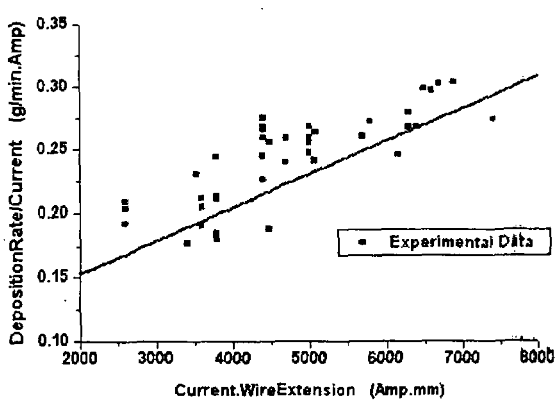


Fig. 2 Relationship between welding current, wire extension and deposition rate (Flux cored wire, 1.4mm dia.)

$$V_D = b_1 \cdot I + b_2 \cdot I^2 \cdot l_K \quad (3)$$

$$\frac{V_D}{I} = b_1 + b_2 \cdot I \cdot l_K \quad (4)$$

Deposited area consists of 3 parts as shown in Fig. 2. It may be written by equation 5. The deposited area can be also expressed by equation 6 with welding speed V_S and deposition rate V_D. Equation 7 and 8 are obtained from equation 3 and 6. Welding speed Vs is determined by equation 8.

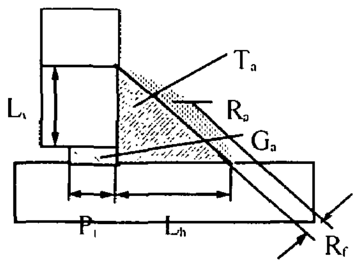


Fig. 3 Deposition area

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

where

$$T_a = L_h \cdot L_v / 2$$
$$R_a = \sqrt{L_h^2 + L_v^2} \cdot R_f \cdot 2/3$$
$$G_a = P_t + R_g$$

3. Fuzzy system

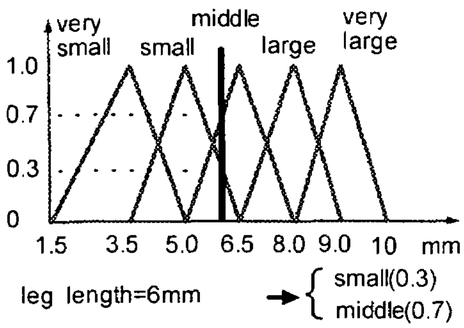
Fuzzy system has ability to work with uncertain information. It is very useful tool for solving many uncertain problem in welding technology[4][5]. In this research it was used for deciding the proper reinforcement area and welding current. In general, as leg length is larger and root gap is smaller, reinforcement area is larger and higher welding current can be used. 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 middle and root gap is large, **Then** reinforcement area is small and applicable current is low.*

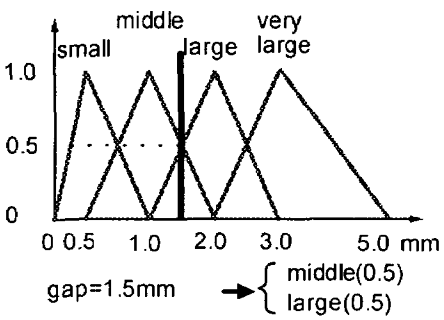
Although the empirical knowledge is an useful information, it can give no guidance for definite values of optimal reinforcement area and welding current. Fuzzy system gives reasonable definite values of them from the above rules. Fig. 8 shows estimating process of welding current. Fig. 4(a) is fuzzy rules which come from empirical knowledge. Fig. 4(b)-(f) show definition of fuzzy sets for leg length, root gap and welding current, and approximate reasoning process for estimation of welding current. This example shows when leg length is 6mm and root gap is 1.5mm, 230A of welding current is recommended. If the reinforcement area and the welding current are determined by fuzzy system, welding voltage and travel speed are obtained from equation 6 and 8.

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

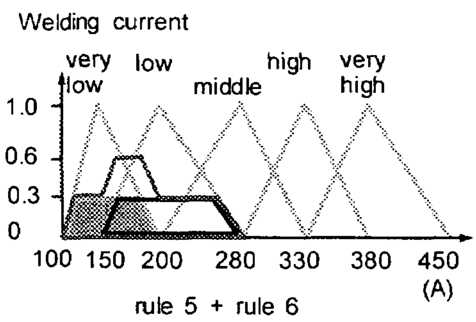
(a) Fuzzy rules



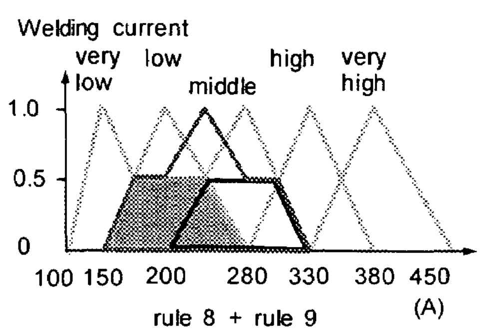
(b) Evaluation of leg length by fuzzy set



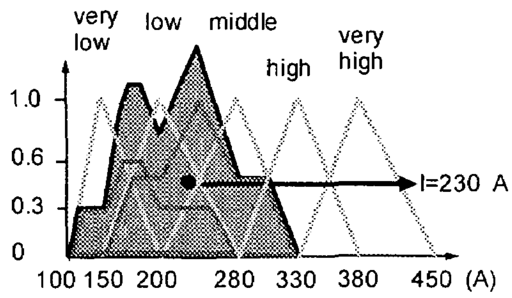
(c) Evaluation of root gap by fuzzy set



(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

$$A_{DEP} = \frac{V_D \cdot 100}{V_S \cdot \rho} \qquad (mm^2) \qquad (6)$$

$$V_D = A_{DEP} \cdot V_S \cdot \rho / 100$$

$$= b_1 \cdot I + b_1 \cdot I^2 \cdot l_K \qquad (g/\mathrm{min}) \qquad (7)$$

$$V_S = \frac{(b_1 \cdot I + b_1 \cdot I^2 \cdot l_K) \cdot 100}{A_{DEP} \cdot \rho} (cm/\mathrm{min}) \qquad (8)$$

4. Prediction of bead shape using neural network

Weld bead shape is influenced by a lot of welding parameters. In this research the welding current, voltage, speed, weaving width and root gap are considered as main parameters influencing bead shape. Fig. 5 shows their influence on the bead shape. However, these relationships can not be expressed by mathematical function because they contain high complexity and many unknown factors. Artificial neural network gives a solution to this problem[6][7]. The complicated relationships between welding parameters and bead shape can be established by self learning function of the neural network. The neural network system in this study uses a 3-layer back propagation model and generalized delta rule as learning algorithm. Fig 6 shows the structure of the neural network model. The input layer has 5 neurons which mean current, voltage, speed, weaving and root gap.

The hidden layer has 5 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. 40 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 2 examples of the comparison.

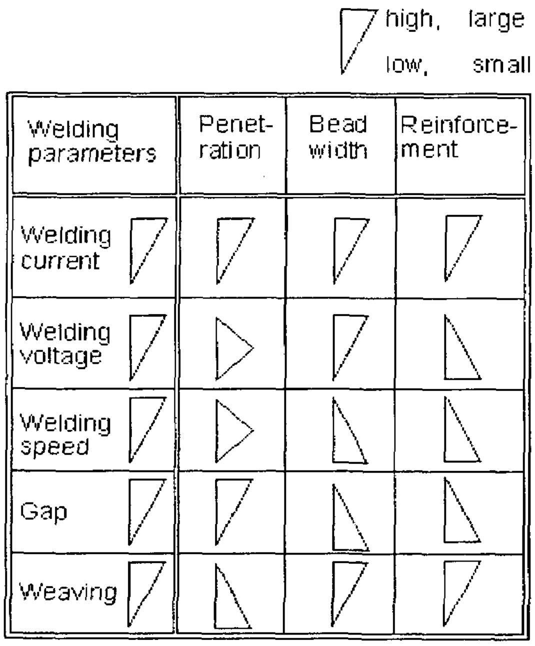


Fig. 5 Influences of welding parameters on the bead shape

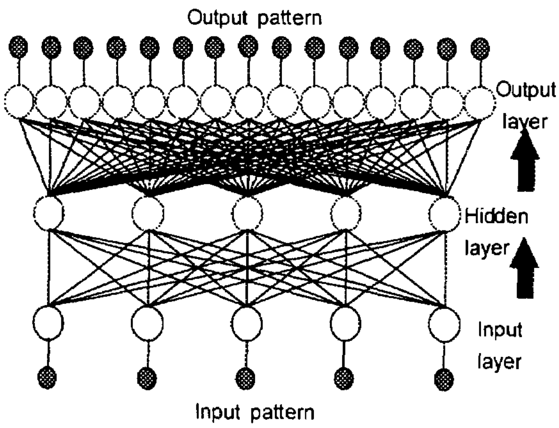


Fig. 6 Structure of neural network model for prediction of bead shape

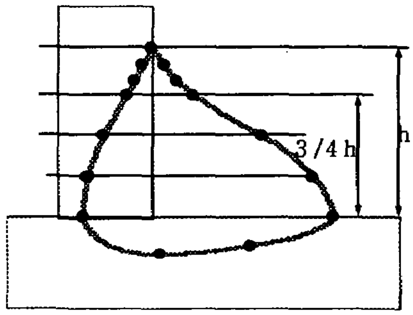
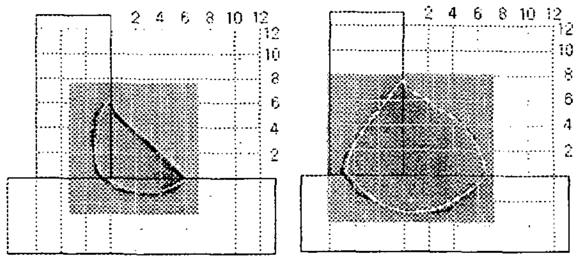


Fig. 7 Selection of 15 points to draw a bead profile



(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 knowledge base system

Optimization is an adjustment of parameters for correction of undesirable weld bead. Undesirable bead containing weld defects result 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, which parameters should be changed and how much they must be adjusted. Fig. 9 shows the flow chart of the optimizing process. The parameter values of the undesirable bead in Fig. 8(b) was optimized to 330A, 30V, 44cm/min. The corrected bead is shown in Fig. 10.

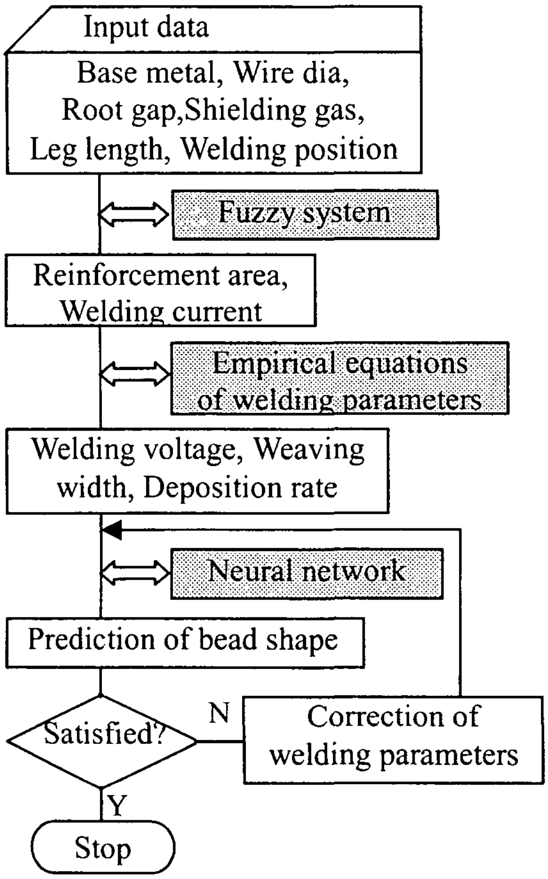
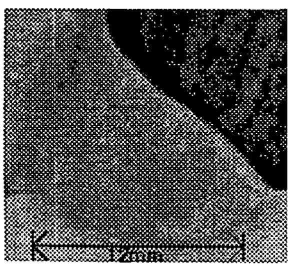


Fig. 9 Flow chart of optimization



Current = 330A
Voltage = 30V
Speed = 44cm/min

Fig. 10 Corrected bead by optimization

6. Structure of 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.

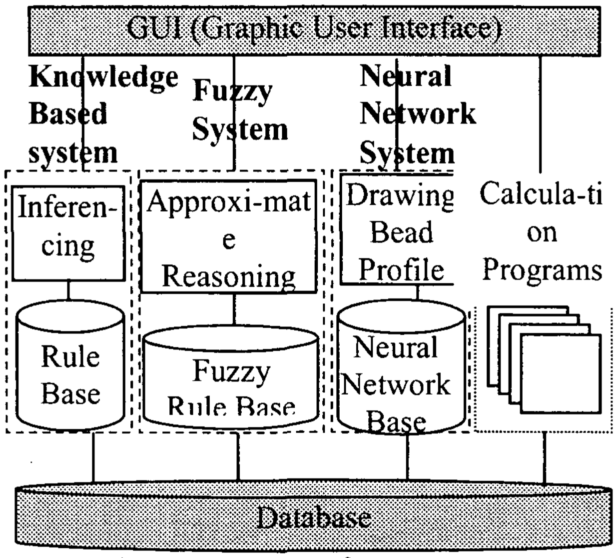


Fig. 11 Structure of expert system

7. Summary and Conclusions

CO2 robotic arc welding requires definite values of welding parameters. But, it is very difficult because welding is a highly complex and nonlinear process. This study shows an expert system can be a good 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 knowledge based system. The test welding showed the validity of the developed expert system.

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