Using neuro-fuzzy system for plate forming in shipyards

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A concurrent Neuro-Fuzzy model is proposed to generate information on the necessary heating lines to form steel plates using the line heating method. A set of experimental data for the bending angle produced by a single heating line for certain heating conditions are used to train the neural network. The trained neural network is employed to decide the heating conditions such as torch speed as well as the bending angle for certain plate thickness and certain radius of curvature. Based on the bending angle obtained from the neural network with the radius of curvature, the fuzzy logic model gives decision on the appropriate number of heating lines necessary to bend a flat plate into a uniform single curved surface. The accuracy of the proposed concurrent neuro-fuzzy model is examined. In addition, the information generated from the proposed concurrent neuro-fuzzy model, torch speed and number of heating lines for certain plate thickness and desired radius of curvature, is then applied experimentally in forming a sample flat plate into uniform single curved surface using the line heating method. Satisfactory agreement between the target shape of the plate and that formed by the line-heating method, based on instructions decided using the proposed neuro-fuzzy model, is obtained.

في هذا البحث تم اقتراح استخدام نظام هلامي-عصبي متزامن لاستخراج معلومات عن خطوط التسخين اللازمة لتشكيل الألواح باستخدام طريقة التسخين الخطي. تم استخدام بيانات معملية عن زاوية الثني الناتجة نتيجة تطبيق طريقة التسخين الخطي لعدد من حالات التسخين المختلفة في تدريب الشبكة العصبية. وهذه الشبكة العصبية المتدربة توظف في تحديد حالة التسخين مثل سرعة بوري التسخين وزاوية الثني الناتجة من هذا التسخين لسمك معين من الألواح الحديدية. اعتمادا علي قيمة زاوية الثني المقدرة بواسطة الشبكة العصبية مع نصف قطر التقوس المطلوب في تشكيل اللوح يتم استنتاج عدد خطوط التسخين اللازمة لتشكيل اللوح باستخدام نظام المنطق الهلامي بعد إعداده لهذا الغرض. تم اختبار دقة النظام الهلامي-العصبي المتزامن في استنتاج المتغيرات المطلوبة. كذلك تم استخراج المعلومات اللازمة لتشكيل لوح حديدي مستوي بواسطة النظام المقترح وتم عمل تجربة معمليه باستخدام طريقة التسخين الخطي. هذا وقد تبين من التجربة أن شكل اللوح الناتج من التشكيل في حاله تطابق مقبول مع الشكل المطلوب الوصول إليه.

Keywords: Neural network, Fuzzy logic, Concurrent neuro-fuzzy model, Line-heating method, Bending angle

1. Introduction

Forming shell plate of ship structure is usually accomplished using the line-heating method. This versatile method can be applied to form complicated shapes that could not be achieved using the mechanical methods. The plate formed by the line-heating method is bent under the influence of the bending and/or inplane plastic deformation created during the heating and cooling cycle. Skills and experience of worker are considered the indispensable elements to carry out the plate bending by the line-heating method. To overcome the shortage for this kind of workers especially in developing countries, the unrevealed skill and experience of workers should be determined using other methods. Numerous research works had been carried out toward real application of the computer technology in plate forming by the line-heating method [1-8]. Once the necessary information about the forming process by the line-heating method can be accumulated with the aid of computer, the line-heating method can be put into practical use in shipyards.

The new computing techniques such as Artificial Neural Network (ANN), Fuzzy Logic (FL), and Genetic Algorithms (GA) have wide spread applications in different fields. The contribution of these techniques can be complementary, subsequently; it would be advantageous to use these mathematical techniques together to form a hybrid system that combines their advantages. Soft computing is the development of these hybrid systems that are also known as neuro-fuzzy computing [9-10]. This technique uses the power of artificial neural networks that classify patterns in data and adapt that classification with highly dynamic environments. In addition, fuzzy inference systems are an extension of classical artificial intelligent techniques which incorporate human knowledge and perform uncertain reasoning. It is based on the idea that sets are not crisp but some are fuzzy, and these can be modeled in linguistic human terms such as large, small and medium. The combination of artificial neural network and fuzzy sets offers a powerful method to model human behavior. In some cases genetic or evolutionary algorithms which are derivative-free optimization techniques may be applied to further complement the hybrid system especially in the artificial neural network. There are several ways for combining the ANN and fuzzy logic [11], as follows:

i. Fuzzy-Neural network system: the fuzzy methods are employed to enhance the learning capabilities or performance of the ANN,

ii. Concurrent Neuro-Fuzzy system: the ANN and the fuzzy system work together on the same task without any influence on each other. The neural network modifies the output of the system and/or produces the input for fuzzy logic system,

iii. Cooperative Neuro-Fuzzy system: the ANN determines off line membership functions, fuzzy rules, or fuzzy weight and then is not used any more, and

iv. Hybrid Neuro-Fuzzy system: ANN and fuzzy are combined into one homogeneous architecture such that it can interpret ANN with fuzzy input, weight, output, and activation functions.

The concurrent neuro-fuzzy system is applied, in this paper, to generate information on plate forming by line-heating. The neural network part of the model is used to decide the torch speed and the associated bending angle as an input for fuzzy logic part which determines the number of heating lines. Experimental data for torch speed and plate thickness with the induced bending angle and shrinkage produced for plate samples using a single heating line is used to train the neural network. Then the trained neural network is employed to decide the torch speed and associated bending angle for certain plate thickness and radius of curvature. The obtained bending angle from the neural network with the radius of curvature are used by the fuzzy logic part of the model to generate information on the appropriate number of heating lines to bend a flat plate into uniform single curved shape. The accuracy of the proposed neuro-fuzzy model is examined.

In addition, the line heating method is used to form a flat plate sample so as to reach the desired shape based on the predicted number of heating lines with the torch speed. The accuracy between the target shape of the plate and that formed by the line heating method, based on the generated information using the proposed concurrent neuro-fuzzy model, is shown to be satisfactory in shipbuilding industry.

2. Plate bending by line heating

2.1. Shape of bent plate by line heating

By moving an oxy-acetylene torch on a plate parallel to its length at its mid-width from one end to the other, the plate is bent in the transverse direction bending angle θ_L around the heating line as shown in fig. 1. The magnitude of the induced bending angle θ_L depends mainly on the heat input rate, torch speed, initial stresses, and thickness of plate. This bending angle is considered the effective tool for the line-heating method to form a flat plate into a curved surface in one direction.

The influence of the distance between each heating line on the magnitude of bending

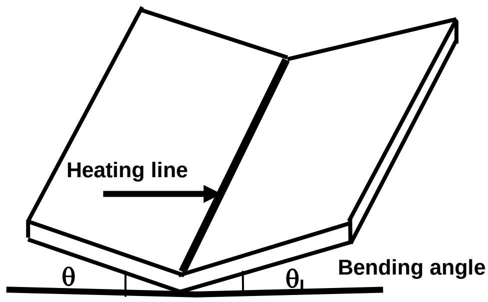

Fig. 1. Shape of bent plate in transverse direction to heating line.

angle produced by the preceding one had been studied by Hashimoto [12]. Hashimoto had conducted several experiments to study the effect of distance between each heating line on the magnitude of the induced bending angle θ_L. He concluded that as long as the distance between each heating line is greater than 50 mm there will be no effect on the magnitude of created bending angle θ_L. In addition, Rashwan [5], using thermal-elastic-plastic FEM model, showed that there can be only bending angle in the transverse direction to heating line at certain torch speed and the longitudinal one diminishes. Hence, for plate bending by the line heating method, the following assumptions can be made:

1. Each heating line can create a constant transverse bending angle θ_L along its length.
2. Inplane shrinkage effect will be neglected such that the desired surface is considered to be a developable surface.

Thus forming of a flat plate into a single curved surface can be thought as dividing the flat plate into several strips and rotating every two adjacent strips around their line of conjunction a certain angle θ_L to approach the required curved shape as shown in fig. 2. Consequently, the problem of approaching the required curved form can be treated by methods of geometry instead of continuum mechanics.

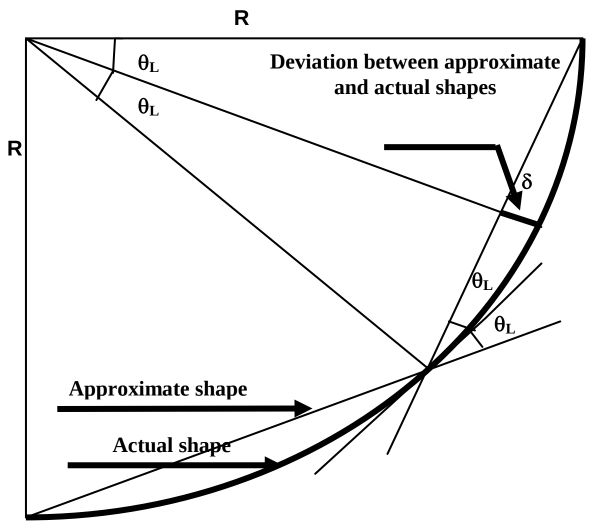

Fig. 2. Approximating actual shape by dividing flat plate into certain number of divisions simulating plate bending by each heating line.

2.2. Number of heating lines

It can seen from fig. 2 that as the magnitude of the bending angle θ_L increases, the width of the strip increases leading to a decrease in number of heating lines NOHL. In addition, the deviation of the approximate shape, δ, from the target curve increases. The magnitude of deviation depends on the radius of curvature and the bending angle θ_L such that:

$$\delta = R(1 - Cos\theta_L)\ , \tag{1}$$

where, R = the desired radius of curvature (M),
θ_L= the bending angle produced by single heating line.

Depending on the desired radius of curvature R and the permissible deviation δ_{per}, the bending angle θ_L obtained from the line heating method should satisfy the relation:

$$\theta_L \le Cos^{-1}(1 - \frac{\delta_{per}}{R})\ . \tag{2}$$

Based on the geometry given in fig. 2 it can be shown that, for a unit width of plate, the number of heating lines, NOHL, may be approximated by the following relation:

$$NOHL \cong (\frac{1}{2R\theta_L} - 1)\ , \tag{3}$$

where the bending angle θ_L is in radians and the radius of curvature R is in meter.

2.3. Experimental data

Different plate samples, steel A37, of different thicknesses with oxy-acetylene heat source were used to carry out experiments to determine the magnitude of the bending angle θ_L at different torch speeds [7]. The size of the sample plates was 450mm×300mm with three different thicknesses (h) 12, 16 and 20 mm. In addition, several samples for each plate thickness are considered to study the effect of torch speed (v) on the produced bending angle (θ_L). The description of used equipment and the procedure for carrying out the experiments are given in ref. [7]. The result of measurements for the bending angle θ_L is shown in table 1.

The suitable bending angles with the torch speed, based on eq. (2), to produce 0.25 mm deviation for radius of curvature up to 30 meter are given in table 2. This data for the bending angle and torch speed for different radius of curvature and plate thicknesses are used to train the neural network.

3. Neuro-fuzzy modeling

The concurrent neuro-fuzzy model is adopted so as to make decision on plate bending by line heating method. In this model, ANN receives two variables, plate thickness and desired radius of curvature and then sends the torch speed, as a system output, and bending angle θ_L as input for the fuzzy logic, shown in fig. 3. Then, the fuzzy logic receives the bending angle and the radius of curvature as input variables and predicts the number of heating lines, NOHL, as output of the model as shown in fig. 3.

3.1. Neural network

A simple three layers feed forward neural network, shown in fig. 4, is used in the proposed Neuro-fuzzy system. The input layer has two variables, namely; plate thickness, h, and desired radius of curvature, R. In addition, the output layer has two variables;

Table 1
Measured bending angle due to single heating line [7].

h (mm)	v (mm/s)	θ_L (deg)
12	1	1.2
	2.5	1.32
	5	0.61
	7	0.57
16	2.5	0.61
	3.5	0.50
	5	0.42
	7	0.11
20	1.5	0.78
	2.5	0.46
	3.5	0.40
	5.0	0.20

Table 2
Suitable bending angle and torch speed for given plate thickness and radius of curvature used in training the neural network.

Radius of curvature R (m)	Plate thickness h=12 mm		Plate thickness h=16 mm		Plate thickness h=20 mm	
	θ_L (deg)	v (mm/s)	θ_L (deg)	v (mm/s)	θ_L (deg)	v (mm/s)
2	1.2	2.5	0.61	2.5	0.79	1.5
4	0.61	5	-	-	-	-
5	0.57	7	0.5	3.5	0.46	2.5
10	-	-	0.42	5	0.42	3.5
20	-	-	0.11	7	0.2	5
30	-	-	0.11	7	0.2	5

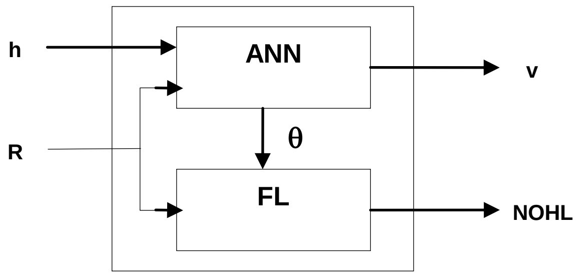

Fig. 3. Input and output variables for the proposed concurrent neuro-fuzzy model.

the torch travel speed, v, and the associated bending angle, θ_L. The hidden layer has certain number of neurons depending on the number of training sets used to learn the neural network. In this case, the number of neurons for the hidden layer equals 9 neurons. Each activated value for the hidden and output layers, respectively, can be calculated such as follows:

$$N_J = F(W_{RJ} \times R + W_{hJ} \times h + W_{BJ}), \quad (4)$$

$$\theta_L = F(\sum_{J=1}^{J=9} W_{J\theta} \times N_J + W_{B\theta}), \quad (5)$$

$$\upsilon = F(\sum_{J=1}^{J=9} W_{JV} \times N_J + W_{BV}), \quad (6)$$

where:

N_J is the activated value of hidden neuron J,

W_{ij} is the weight value of connection between any two neurons i and j in two successive layers as shown in fig. 4,

W_{BK} is the bias weight multiplied by one for any neuron k as shown in fig. 4, and

$F(x)$ is the activation function, sigmoid function is used in the proposed system $= \frac{1}{1+e^{-x}}$.

The neural network is learned through showing a set of inputs and outputs, given in table 2, to the network. The network can self-adjust to produce consistent responses using a supervised learning algorithm and the most popular one is so called backpropagation [13-14]. In this work, the scaled conjugate gradient backpropagation algorithm is used to train the multilayer feed forward network [15].

The maximum absolute error percent of the training process for the neural network, after 1120 epoch, is given in fig. 5 for each output variable that is less than 1 percent. In addition to this good accuracy, the neural network can be updated to accommodate new data for heating conditions, plate thicknesses and induced bending angle from single heating line. This can be done with the incremental training technique, and therefore the neural network can catch any changes in the shipyard's trend.

3.2. Fuzzy logic

Fuzzy logic starts with the concept of a fuzzy set which was introduced by Zadeh [16]. It is the mathematical technique that greatly enhances the capability of classical set theory by allowing the "degree of membership" or "truth value" to range over the interval of 0 to 1. For example, a fuzzy set A on the universe U is a set defined by a membership function $\mu(x)$ representing a mapping such that:

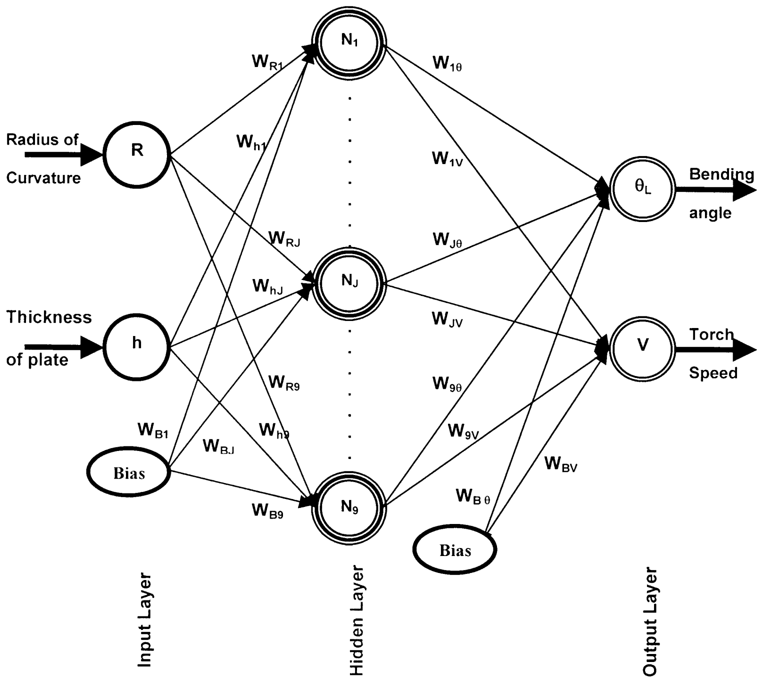

Fig. 4. Input and output variables for simple feedforward neural network topology.

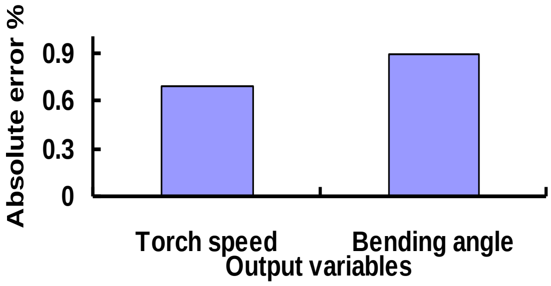

Fig. 5. Percent of absolute error for training data.

$$\mu(x) : U \rightarrow \{0,1\}, \quad (7)$$

where the value $\mu(x)$ for the fuzzy set A is called the membership value of $x \in U$. The membership value can be interpreted as the degree of x belonging to the fuzzy set A. For the considered neuro-fuzzy system, three fuzzy sets are considered, bending angle set, θ_L, radius of curvature set, R, and number of heating lines set, NOHL.

Four operations should be performed by a fuzzy system namely; fuzzification, activation of fuzzy rules, fuzzy inference, and defuzzification as shown in fig. 6. The input and output variables, information at hand, of the fuzzy logic are first fuzzified. This is done through transforming the crisp values of these variables into membership in fuzzy sets that determine their membership value for these fuzzy sets. Fig. 7 shows the developed membership functions for the radius of curvature R, the bending angle θ_L and the number of heating lines NOHL, respectively.

Fuzzy rules include the traditional IF-THEN format that interprets the input information obtained from the fuzzification procedure. In general, a fuzzy rule has the form:

$$IF\ X_1\ is\ A_1\ AND\ldots OR\ X_m\ is\ A_m\ THEN\ Z\ is\ B, \quad (8)$$

where X_i and Z are fuzzy variables and A_i and B are fuzzy sets. Other types of logical operators such as NOT can be used in fuzzy rules.

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The fuzzy logic inference engine determines the activating level of each fuzzy set in the consequent of activating each fuzzy rule. Two common approaches are used in fuzzy logic inference: the correlation-minimum and correlation-maximum [17] and the former approach is applied in this work.

Defuzzification is the process that determines the exact numerical value of output from the information contained in the output fuzzy sets. Several procedures are available and the centroid defuzzification, the wide used one, is applied.

The predicted number of heating lines per unit width of plate using the proposed fuzzy logic model is shown in fig. 8 for different values of radius of curvature. The maximum error associated with this prediction does not exceed 4% which reflects the accuracy of the proposed neuro-fuzzy system.

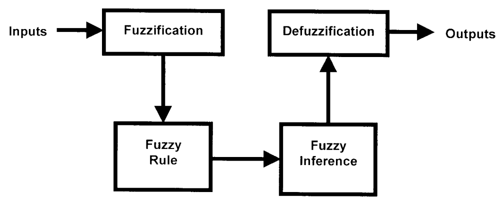

Fig. 6. Schematic of fuzzy system.

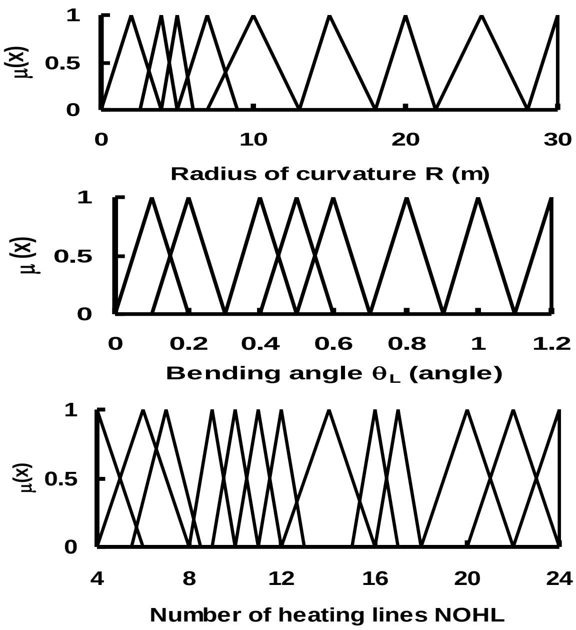

Fig. 7. Fuzzy membership functions.

4. Case study

4.1. Sample plate and target shape

A sample plate of dimension 2000×1000×12mm made from ordinary steel of grade A37 is used in the experiment. A part of uniform curved open cylindrical surface with radius of curvature, *R*, equal to 4000mm, is considered as a target shape. The width of the plate is chosen as the forming direction. Since the desired radius of curvature is constant along the length of plate, straight heating lines parallel to that direction are considered enough in forming plate. However, the number of heating lines must be decided before using the line heating method in the experiment.

4.2. Number of heating lines

To form the previous flat plate into the uniform curved surface, it is necessary to know the number of heating lines. The trained neural network, based on the training data given in table 2, is used to predict the bending angle and the corresponding torch speed for the considered thickness of sample plate, *h* is 12mm and the required radius of curvature, *R* is 4 meter. The obtained magnitudes of the bending angle θ_L and the torch speed are 0.61 degree and 5mm/sec, respectively. The error in predicted values using the neural network is less than 0.01 percent since this data set is applied during the training stage.

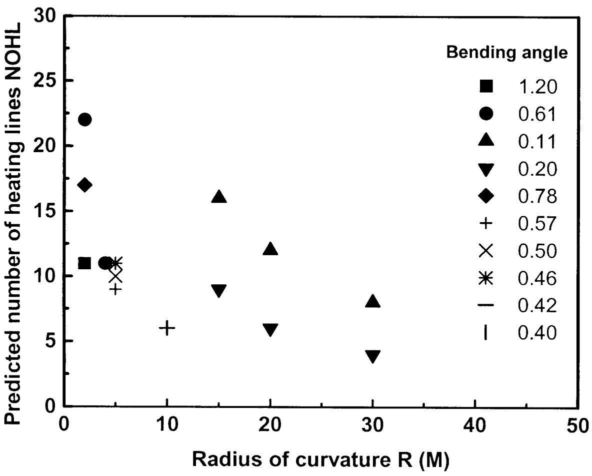

Fig. 8. Predicted number of heating lines NOHL using the proposed fuzzy logic for different radius of curvatures.

To estimate the number of heating lines, the fuzzy logic part of the model is employed. Based on the obtained bending angle, 0.61 degree, and desired radius of curvature, 4m, the fuzzy logic model proposed in this research estimates that 11 heating lines are necessary to complete the forming process as given in fig. 8. The heating lines are marked in the length direction of the plate such that the plate is divided into equal strips in the width direction.

4.3. Experimental results

The heating lines were performed sequentially such that the plate was left to cool before starting to heat a new line. After completing the eleven heating lines, the deflection of the plate was measured at three sections, two edge sections and middle section, equally spaced in the longitudinal direction. The procedure of measurements is described in detail in ref. [7]. The produced shape of plate due to applying the line heating method is compared with the target shape as shown in fig. 9 at the considered sections. It is clear from fig. 9 that the shape of plate obtained by line heating method deviates very slightly from the target shape. In addition, it can be seen from fig. 9 that the produced shape of plate is over bent. However, the maximum error between the obtained and target shapes varies
shape by using the line heating method for sample plate.
is 3.5mm, about 11%, at the middle of the plate. According to the International Association of Classification Societies (IACS) [18] and

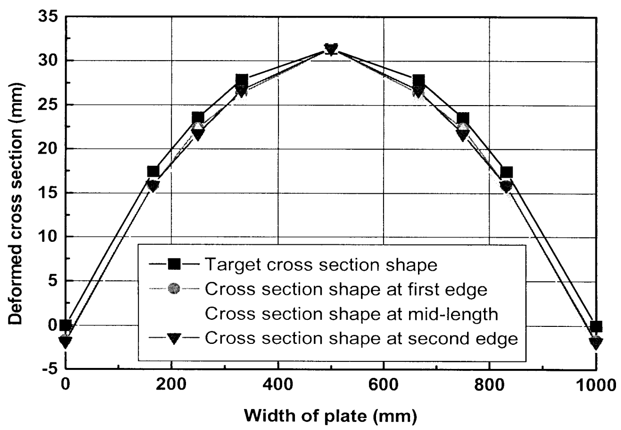

Fig. 9. Comparison between target shape and obtained

Japan Shipbuilding Quality Standards [19], the tolerance limits between the curved shell plate and the template are ± 8mm and ± 5mm, respectively. Consequently, the maximum induced error in the resulting shape is within the tolerance limit even for the Japanese shipbuilding yards. Thus, based on decisions obtained from the proposed neuro-fuzzy model, a satisfactory agreement between the shape formed by line-heating method and the target shape can be obtained.

5. Conclusions

From the present study, the following conclusions can be drawn:

1. Forming flat plate into a single curved surface can be approximated based on geometry rather than continuum mechanics.
2. The concurrent neuro-fuzzy system approach has the ability to decide the torch speed and the number of heating lines necessary to bend flat plate into uniform single curved surface.
3. Formed plate, based on the determined number of heating lines with torch speed, shows satisfactory agreement with the target shape.
4. The used approach in determining the number of heating lines to bend flat plates into single uniform curved surface is quite reasonable.
5. Finally, the ability of neural networks and fuzzy logic to accurately learn and predict nonlinear multiple input and output relationships make them a promising technique in automating the shipbuilding industry.

Acknowledgments

The author would like to express appreciation to Alexandria Shipyard for their support in doing the experiments. Also, the author would like to thank Eng. Ghaleb Y. Ahmad for his assistance in carrying out the experiment.

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Received January 4, 2004
Accepted April 14, 2004