International Journal of Engineering, Mathematical and Physical Sciences
ISSN: 2517-9934
Vol:9, No:9, 2015

Comparative Study of Bending Angle in Laser Forming Process Using Artificial Neural Network and Fuzzy Logic System

M. Hassani, Y. Hassani, N. Ajudanioskooei, N. N. Benvid

Abstract**—**Laser Forming process as a non-contact thermal forming process is widely used to forming and bending of metallic and non-metallic sheets. In this process, according to laser irradiation along a specific path, sheet is bent. One of the most important output parameters in laser forming is bending angle that depends on process parameters such as physical and mechanical properties of materials, laser power, laser travel speed and the number of scan passes. In this paper, Artificial Neural Network and Fuzzy Logic System were used to predict of bending angle in laser forming process. Inputs to these models were laser travel speed and laser power. The comparison between artificial neural network and fuzzy logic models with experimental results has been shown both of these models have high ability to prediction of bending angles with minimum errors.

Keywords**—**Artificial neural network, bending angle, fuzzy logic, laser forming.

I. Introduction

LASER forming process is one of the modern forming processes in which the laser beam moves over the surface of a sheet at specified speed and creates a thermal gradient along the thickness of the sheet. It results the thermal stresses along the sheet thickness, causing plastic deformation of the sheet in the heated area. Iterating the beam movements in a defined path, the produced bending increases, and finally a permanent bend is resulted in the sheet [1]. This process is applied extensively in forming metal and non-metal sheets which used in aerospace, shipbuilding and automobile industries [2]-[5]. Some researchers have been studied laser forming process, such as Edwardsen et al. which have been investigated the effect of clamping the piece on the bending angle [6]. Yanjin et al. have been studied the effect of material properties on the forming of metal sheets [7]. Peng Cheng et al. has been investigated the effect of the different sheet thickness on the bending angle in this process [8]. Also, several studies have been conducted on the effect of the laser beam motion on the surface of the sheet and the resulting bending angle using empirical formula [9]-[12]. Kyrsandy [13] and Cheng Li [14] have been examined the effect of two-dimensional and three-dimensional heat transfer on the bending angle. Jiu Wang [15], Cheng [16], and Simin Fu [17] have been provided a model to predict the bending angle using artificial neural networks (ANN).

The present article tries to provide models to predict the bending angle resulted from the laser forming process, using artificial neural network and fuzzy logic system. The results from these two models were compared to the experimental data [18], and the rate of error was reported for both models. Fig. 1 shows the laser forming process schematically.

M. Hassani, Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Isfahan, Iran, CO 3514143131 Iran (Phone: +989132231972; Fax: +983134431043; e-mail: m.hasanee@smc.iaun.ac.ir, m.hasanee@yahoo.com).

Y. H. is with the Department of Textile Engineering, Yazd Branch, IslamicAzad University, Yazd, Iran (e-mail: yhassanee@yahoo.com).

N. A. and N. N. B are with the Department of Mechanical Engineering, Roudehen Branch, Islamic Azad University, Roudehen, Tehran, Iran. (e-mail: neda_oskoei@yahoo.com, noorosadat@gmail.com).

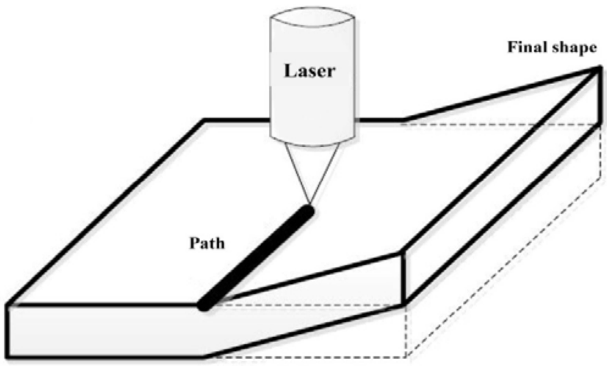

Fig. 1 The schematic of laser forming process

II. Experimental Setup

Empirical experiments were done on the Steel alloy 1.0586 (D3). Laser device which used in the operation is the Co2 type. Laser power and laser speed parameters were considered as input parameters and the bending angle as the output parameter. Process parametric study was conducted by performing 27 data points. Material properties and parameters of laser are shown in Table I.

TABLE I
MATERIAL PROPERTIES AND LASER PARAMETERS OF PROCESS

Factors	Values
Length	300 mm
Width	150 mm
Thickness	6 mm
Laser beam diameter	16 mm
Absorption coefficient	30 %
Specific heat	427 J/Kg.℃
Thermal conductivity	35.1 W/m.℃
Thermal expansion	12e-6 1/℃
Density	7860 Kg/m^3

III. Artificial Neural Network

Artificial neural network is an approach which tries to follow the special processing abilities of human brain. This machine learning technique can learn the existing patterns in data using massive parallel processing. Artificial neural network features include the ability to learn, generalize, and parallel processing. Each artificial neural network consists of three layers: input, hidden, and output. There are a number of neurons in input and output layers according to input and output parameters, and the number of neurons in the hidden layer should be calculated with trial-and-error process. A lot to learn algorithms have been proposed for the learning of network (network training) which the most important is TrainLM function. The artificial neural network which used in this study is Feed Forward Back Propagation (FFBP) with 2-7-1 topology. It means that, there are 2, 7, and 1 neurons input hidden and output layers respectively. The schematic of the artificial neural network is shown in Fig. 2.

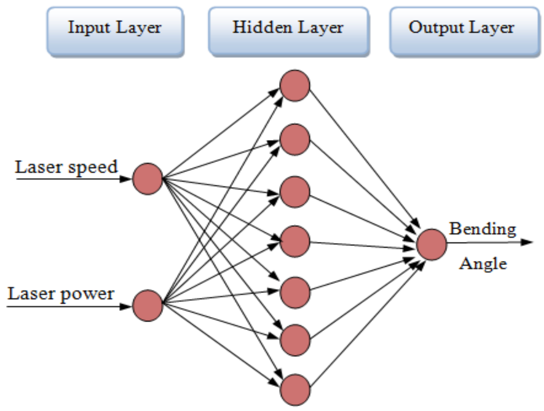

Fig. 2 The schematic of the artificial neural network

Selected transfer function in the hidden and output layers is Tansig. The equation of tansig transfer function expresses in (1):

$$f(x) = \frac{2}{1+e^{2x}} - 1 \quad (1)$$

The experimental data were normalized before entering the network using (2). The experimental data points were divided to 80% and 20% for training and testing steps respectively.

$$X_{norm} = \frac{X - X_{min}}{X_{Max} - X_{min}} \quad (2)$$

IV. Fuzzy Logic System

Fuzzy inference system (FIS) is a process which adapts inputs (single or multiple) to outputs, using fuzzy logic. There are two types of fuzzy inference systems, mamdani and sugeno. In these two methods, output is determined linearly. In fuzzy models, at first inputs and outputs should be categorized into fuzzy sets. The next step is to select the inputs and to determine the degree their belonging to corresponding fuzzy sets. This is done according to the function of set membership. Then, the relationship between inputs and outputs is determined by the written terms from these sets (fuzzy rules). In fact, these linguistic statements connect fuzzy sets and fuzzy functions, and the fuzzy network can be trained by these rules and infer the relationship between inputs and outputs. In fuzzy logic, inputs are real numbers and outputs are a fuzzy set or an integration of several fuzzy sets. In fact, the integration of fuzzy sets involves a range of output values, and to obtain a numerical specified output value of the sets, they should be deactivated. Defuzzification set determines a specific number for the output [19].

The present study uses the mamdani fuzzy system and Fig. 3 shows the schematic of the model.

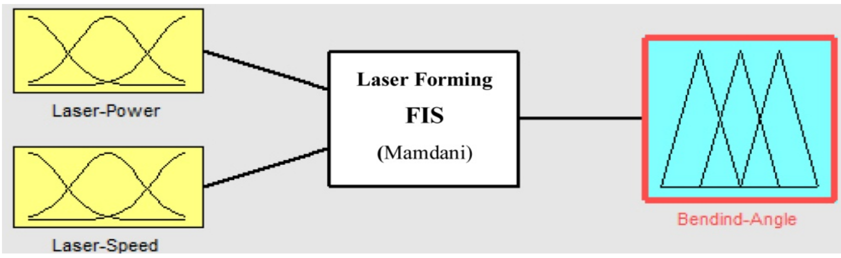

Fig. 3 The schematic of the Mamdani fuzzy logic system

TABLE II
Comparison of Experimental, ANN, and FIS Test Data Sets for Bending Angles

	Factors		Bending Angle (°C)			APE (%)	
No.	Power (KW)	Speed (m/min)	Exp.	ANN	FIS	ANN	FIS
1	3	0.9	0.4	0.403	0.411	0.825	2.750
2	3	1.4	0.62	0.614	0.637	0.968	2.742
3	2	0.3	0.74	0.745	0.763	0.676	3.108
4	1.5	0.3	0.487	0.491	0.473	0.821	2.875
5	1	0.15	0.705	0.698	0.721	0.993	2.270
					MAPE(%)	0.857	2.749

To train the fuzzy model, it was used 80% of data set as in neural network model, and each of input and output parameters is categorized into four or six fuzzy sets. As shown in Fig. 4, the membership function of these sets is as triangular, and also, they are codified using abbreviated letters VVL, VL, L, H, VH, VVH, representing very low, very low, low, high, very high, and very high respectively.

V. Results and Discussion

Table II presents the test data set of the empirical experiments and the predicted values of artificial neural network and fuzzy logic system with each model's errors for test data set. As seen, the artificial neural network with a mean absolute percentage error (MAPE) of 0.857% and fuzzy logic with MAPE of 2.749% show a high ability to prediction of bending angle in laser forming process. As shown in Fig. 5, the regression analysis of the artificial neural network with R2=0.9997 and fuzzy logic system with R2=0.9985 represent a high potential in detecting the correct amounts of bending angle. Considering Fig. 6 indicating the levels generated by the fuzzy logic and the uniform and continuous behavior of the model, it shows the high capability of the fuzzy logic model in predicting the bending angle values.

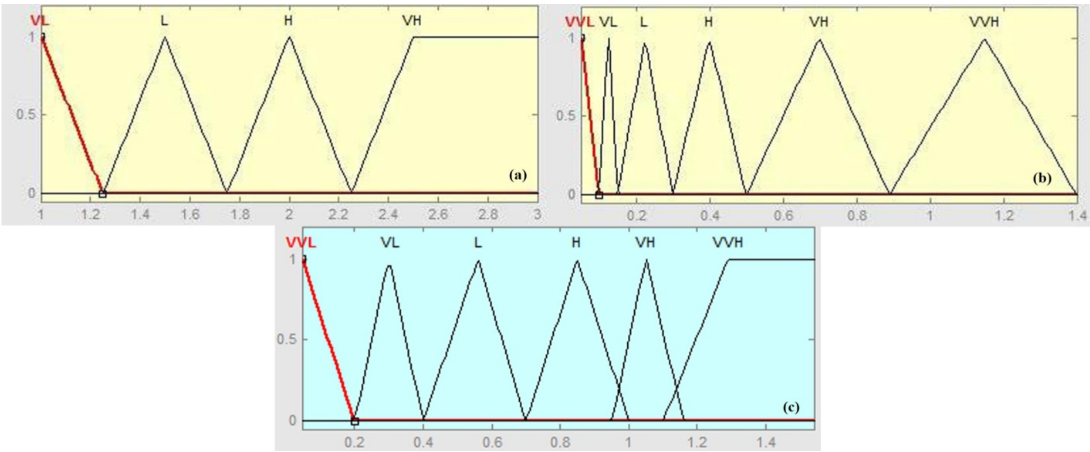

Fig. 4 The membership function of process parameters, (a) laser power, (b) laser speed, (c) bending angle

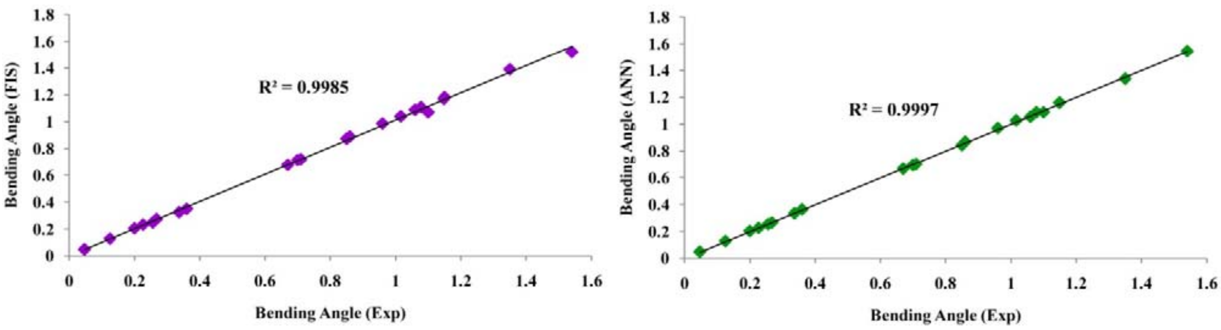

Fig. 5 Regression analysis of ANN and FIS results versus experimental data set

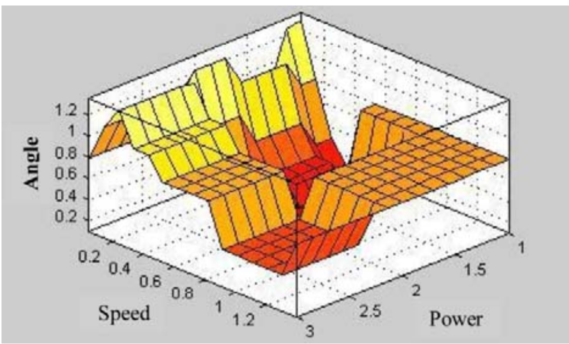

Fig. 6 Generated surfaces by fuzzy logic model

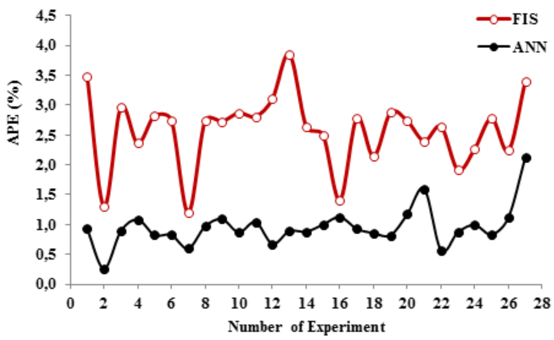

Fig. 7 APE (%) of ANN and FIS results versus number of experiment

If the artificial neural networks and fuzzy logic are trained properly and their accuracy is evaluated, they will have high ability to predicting of bending angle values in the laser forming process, which leads to saving time and cost. Fig. 7 shows the values of absolute percentage error (APE) for artificial neural network and fuzzy logic results. As can be seen, the artificial neural networks with less error values, compared to the fuzzy logic model, shows more ability to predict the bending angle values, although the difference is negligible.

VI. Conclusion

In order to predict the bending angle in the laser forming process, several models were presented in this paper, based on artificial neural network and fuzzy logic system. These models were trained using experimental data and their accuracy was tested. Finally, the values of bending angle were predicted using these two models, and the error values were presented for both models. Considering the mean absolute percentage error of 0.857% and 2.749% for artificial neural network and fuzzy logic models, respectively, it was concluded that the artificial neural network model represents more accurate prediction of the bending angle in the process of laser forming, compared to the fuzzy logic model. It is recommended for further future researches to provide models using the artificial neural network in order to predict thermal distribution along the sheet thickness during the laser forming process.

References

[1] X. Zhand, "Laser Assisted High Precision Bending and It's Applications". PhD Thesis, Faculty of Purdue University, 2004.

[2] G. Dearden, and S.P. Edwardson, “Pure and Applied Optics 5”, *Journal of Optics A*, pp. 8–15, 2003.

[3] H. Shen, and F. Vollertsen, “Modelling of laser forming: An review.” *Computational Materials Science,* Vol 46, pp. 834–840, 2009.

[4] M. Shirani, A. Akbari, and M. Hassani, “Adsorption of cadmium (II) and copper (II) from soil and water samples onto a magnetic organozeolite modified with 2-(3, 4-dihydroxyphenyl)-1,3-dithiane using an artificial neural network and analysed byflame atomic absorption spectrometry”, *Analytical Methods*, DOI: 10.1039/c5ay01269d, 2015.

[5] S. Shakeri, A. Ghassemi, M. Hassani, and A. Hajian, “Investigation of material removal rate and surface roughness in wire electrical discharge machining process for cementation alloy steel using artificial neural network”. *International Journal Fo Advanced Manufacturing Technology*, DOI: 10.1007/s00170-015-7349-y, 2015.

[6] S. P. Edwardson, K. G. Watkins, E. Abed, K. Bartkowiak, and G. dearden, "Geometrical Influences on the Bend Angle Rate per Pass during Multi-pass 2D Laser Forming". *Journal of Physics D: Applied Physics*, pp. 382-389, 2006.

[7] G. Yanjin, S. Sheng, Zh. Guoqun, and L. Yiguo, "Influence of Material Properties on the Laser Forming Process of Sheet Metals", *Journal of Mat. Processing Tech*., 2005.

[8] P. Cheng, Y. Fan, J. Zhang, and Y. L. Yao, "Laser Forming of Varying Thickness Plate- part I". *Journal of Manufacturing Science and Eng.*, pp. 634-641., 2006.

[9] M. Geiger, and F. Vollertsen, "The Mechanism oh Laser Forming", *CIRP Ann*., Vol.42, No.1, PP.301-304, 1993.

[10] F. Vollertsen, "An analytical model for Laser bending", *Journal of Lasers Engineering*, Vol.2, pp.261-276, 1994.

[11] C.L. Yan, K.C. Chen, and W.B. Lee, "Laser Bending of Leadframe Materials", *Journal of Material Processing Technology*, Vol. 82, pp.117-121, 1998.

[12] Y. Shi, H. Shen, Zh. Yao, and J. Hu, “Temprature gradient mechanism in laser forming of thin plates”. *Optic & Laser Technology*, Vol.39, pp. 858-863, 2007.

[13] A. K. Kyrsanidi. Th. B. Kermanidis, and Sp.G. Pantelakis, “An analytical model for the prediction of distortions caused by the laser forming process ", *Journal of Material Processing Technology*, Vol. 104, pp. 94-102, 2000.

[14] P.J. Cheng, and S.C. Lin, “An analytical model to estimate angle formed by laser,” *Journal of Material Processing Technology*, Vol. 108, pp. 314-319, 2001.

[15] X. Wang, and W. Xu, “Parameter prediction in laser bending of aluminum alloy sheet”, *Front. Mech. Eng*, Vol.3, 293–298, 2008.

[16] P.J. Cheng, and S.C. Lin, " Using neural networks to predict bending angle of sheet metal formed by laser", *Journal of Machine Tools & Manufacture*, Vol. 40, pp. 1185–1197, 2000.

[17] Z. Fu, J. Moa, L. Chen, and W. Chen, " Using genetic algorithm-back propagation neural network prediction and finite-element model simulation to optimize the process of multiple-step incremental air-bending forming of sheet metal ", *Journal of Materials and Design*, Vol. 31, pp. 267–277, 2010.

[18] A. K. Kyrsanidi, Th. B. Kermanidis, and Sp. G. Pantelakis, " An analytical model for the prediction of distortions caused by the laser forming process", *Journal of Materials Processing Technology*, Vol. 104, pp. 94-102, 2000.

[19] M.T. Hagan, H.B. Demath, M. Beale, “Neural Network Design”, *PWS Publications*, pp. 167-189, 1996.