Mathematical & Computational Applications, Vol. 2, No. 3, pp. 119-125, 1997

AN INVESTIGATION OF DEEP DRAWING OF LOW CARBON STEEL SHEETS AND APPLICATIONS IN ARTIFICIAL NEURAL NETWORKS

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Abstract: In this study, the deep drawability of SAE 6114, being a low carbon steel, was investigated. The materials with thickness varying from 0.67 mm to 2 mm were subjected to tensile tests and then R (average vertical anisotropy coefficient) and n (stain hardening exponent) values were determined. At the same time, h (the height of the cup) and F (the reaction force) values of the materials were found by subjecting them to Erichsen test. A sheet with 2 mm thickness was cold rolled in 6 different deformation ratios and the tests were applied to it. Results obtained from the tests were compared with each other and ANN application was performed for these results.

It was proved that, there was an ANN solution to obtain new values of % deformation rate and thickness properties of deep drawing of low carbon steel sheets which were found by experiment. The obtained values satisfied our estimation.

1. INTRODUCTION

Material quantity which is scraped due to tear off and similar causes in the formation process, sometimes excesses very much the acceptable level. This situation happens mostly because of usage of the inconvenient material if die design and other reasons is not taken into account. Even the properties in a material which is suitable for the process vary depending on the sort of process, basically they must be strengthened in thinning of plate and rapid hardening.

The most common sheet metal forming processes are used for deep drawing and stretch forming. In several sheet metal forming processes, both forming types are used together. Deep drawing might be defined as the metal shaping process used for shaping flat sheets into cup-shaped articles. The wall thickness of the produced cup is nearly the same as the thickness of the blank sheet. However, when the thickness of the metal sheet is compared with the thickness of product, the thickness decreases in stretch forming, markedly [1,2].

A sheet which has a good drawability characteristic should have high resistance to thickness thinning in the desired cup-shape without a change in sheet thickness when it is formed. R value is a measure of resistance to thinning, it may be determined by tensile test and is the plastic strain ratio of width to thickness in a sheet [1,3,4].

Sheet material which is used to stretch forming should be ductile and uniformly deformed without necking. Strain hardening exponents (n) are a measure of good stretch forming characteristics. Having greater value for n means the desired higher ductile and uniform plastic deformation characteristic. Erichsen test is also a measure of good stretchable. The greater height of the cup shows the higher stretchable characteristics. Another important technique for controlling failure is sheet-metal forming limit diagram (FLD). Deformation and strain rates (n) are the effective parameters for formability of sheets [1,3,4].

Mechanical properties of rolled sheets depend on the direction. Therefore average vertical anisotropy coefficient ($\bar{R}$) is defined as in equation (1).

$$\bar{R} = (R_0 + R_{45} + R_{90}) / 4 \qquad (1)$$

Where anisotropy values are the values at 0 , 45 and 90° angles on the rolling direction of the tested sheet. Deep drawability increases with the increasing average anisotropy values. $\bar{R}$ values are greater than 1.0 in most bcc crystal structured metals of low carbon alloys, average anisotropy values are in the range of 1.35 - 1.96. It can be said that if average anisotropy value is higher than 1.0, the material has good drawability and if smaller than 1.0, the material has poor drawability [6,7].

$$\sigma = K\,\varepsilon^n \qquad (2)$$

Holloman equation (2) is valid at the uniform plastic deformation region for low carbon steel. Strain hardening exponent (n) is a central parameter for stretch forming. The plastically deformed region of material shows higher strain hardening exponents, and this region will have a high resistance to necking. Therefore, the uniform plastic deformation of the shaped sheet occurs. Necking is seen at a particular region in which strain hardening exponents are small and localized at that region . As a result of rapidly thinning, cracks may occur quickly [8,9].

The height of the cup measured in Erichsen's experiment is also another criteria for the stretchability. In this experiment the material was forced until it was torn in the standardized conditions by means of a punch having a spherical tip. The most formable sheets are required to be above a certain height of the cup depending on the thickness of the material. The necessary minimum height of the cup obtained in plates and sheets depending on the material's quality has been given in the standards [10,11].

The results of Erichsen's experiment are interpreted as the values which provide a comparison with the values of any material in its standard rather than using them to standardize the materials. They are commonly used in low carbon steels. The higher value of the height of the cup means the ductility of the material [10,11,12].

Artificial neural networks (ANN) are computing systems whose structures are inspired by a simplified model of the human brain. A typical multilayer (3-layers) feed-forward ANN is given in Table 2. It consists of an input layer, an output layer and a hidden layer. Sets of nodes are arranged in these layers. Activation signals of nodes in one layer are transmitted to the next layer through links which either attenuate or amplify the signal.

For a non-linear relation or a complex pattern between input and output values, ANN is a very powerful estimation method. In most ANN applications, for constructing non-linear transfer functions, usually "back-propagation technique" is used.

During the training stage, the output part of a training pattern is the same as input part and both parts consist of correct measurements of the system. When the neural network is being trained, the connection weights are corrected to minimize the error between the true and estimated values of the measurement variables. In ANN, the weights are the distributed associated memory units and show the current state of the knowledge. In training examples, systems operation measurements are shown with all weights and are distributed among the measurements taken from system operation states. Many training patterns for each neural network are formed by selecting the true values of its corresponding measurement subset from the training examples. Each training pattern represents a training example for its corresponding neural network [13].

An ANN is trained to emulate a function by presenting it with a representative set of input/output functional patterns. The back propagation training technique adjusts the weights in all connecting links and thresholds in the nodes so that the difference between the actual output and the target output are minimized for all given training patterns. For the p^{th} training pattern (p=1,2...p), this is done by minimizing the energy function,

$$E_p = (1/2)\,\Sigma_i\,(d_i - y_i)^2 \qquad (3)$$

with respect to all the weights and thresholds. y_i corresponds to the activation function of the ith neuron in the output layer. d_i denotes the desired target. The corresponding updates for the weights are calculated by using the iterative gradient descent technique.

$$w_{ij}^{new}(h) = w_{ij}^{old} + \varepsilon \partial E_p / \partial w_{ij} + \alpha \Delta W_{ij}(h) \qquad (4)$$

The above algorithm is commonly known as error back propagation. The constant ε is the learning step while the constant is the α momentum gain. (For in this study is $\alpha = \varepsilon = 0.75$) Δw_{ij} indicates the weight change in the previous iteration. Weights are iteratively updated for all P training patterns. The training process may require many such sweeps. Sufficient learning is achieved when the total error function,

$$E_{total} = \Sigma_p E_p \quad p=1,2,3...\,p \qquad (5)$$

summed over the set of all p training patterns goes below a pre-selected value ε. [14]

2.EXPERIMENTS

In this study, we use 6114 quality steel which is produced in ERDEMIR. Materials that have 0.67, 1, 1.2, 1.5 and 2.0 mm thickness are purchased from the market. The chemical compositions of materials are given in Table-1.

Table-1: Chemical compositions of material used in experiment (% weight).

C	Mn	P	S	Cr	Ni	Cu	Mo	Sn	Al	V
0.03	0.003	0.008	0.025	0.01	0.02	0.03	0.004	0.001	0.004	0.001

The sheets are cold-rolled in different ratios. Tensile test specimens prepared according to ASTM E5 were tested (with a load of 10 kN). During tensile tests, grips velocity was taken as constant, 1 mm/min. All tests were performed at room temperature.

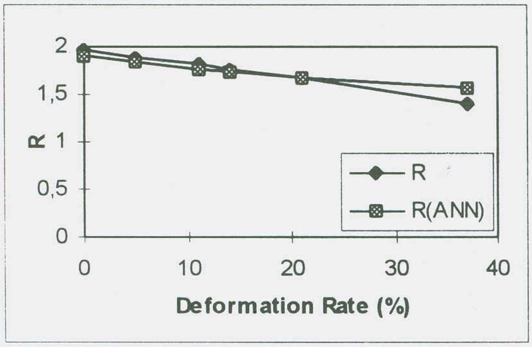

Figure 1: Deformation Rate Versus R, R(ANN).

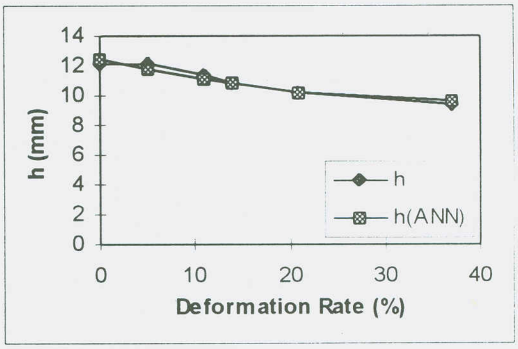

Figure 3: Deformation Rate Versus h, h(ANN).

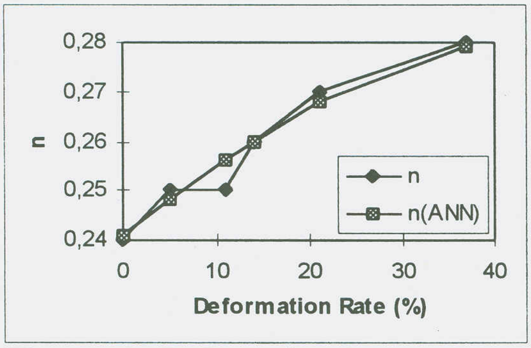

Figure 2: Deformation Rate Versus n, n(ANN).

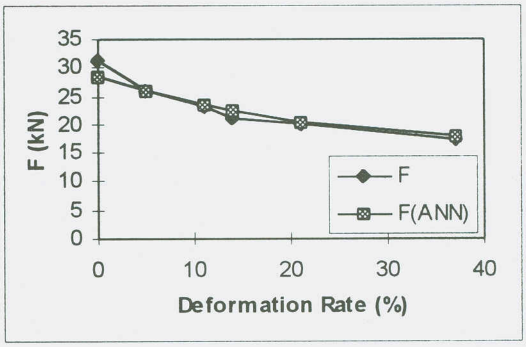

Figure 4: Deformation Rate Versus F, F(ANN).

Using tensile test results, average anisotropy coefficient ($\overline{R}$) and plastic deformation hardening exponent (n) values were calculated. The determined R and n values for tested materials were given in Figure 1, 2.

Strain hardening exponent (n) was determined by using true-strain and true-stress values derived from uniform plastic deformation region of all the tensile tests. All the test results fit to the expected results for these kinds of sheet materials, and some research results.

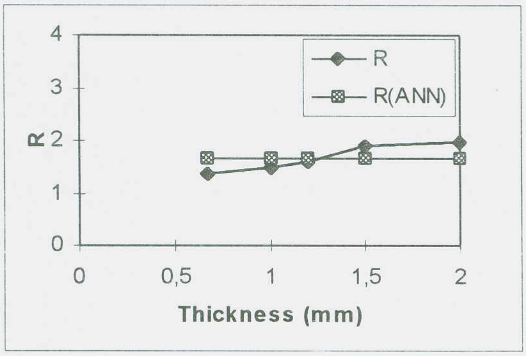

Figure 5: Thickness versus R, R(ANN).

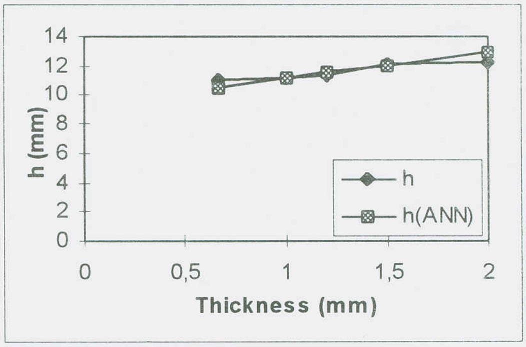

Figure 7: Thickness versus h, h(ANN).

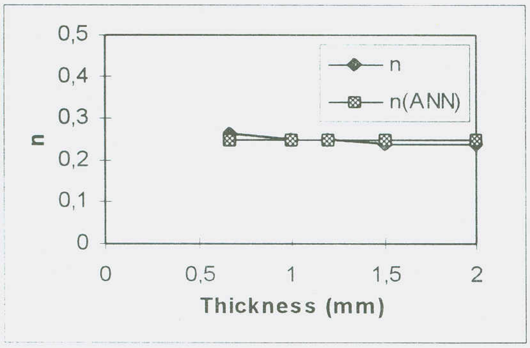

Figure 6: Thickness versus n, n(ANN).

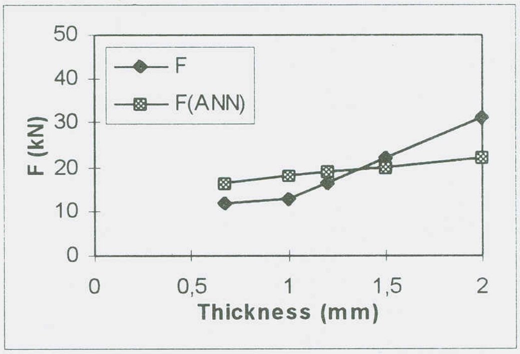

Figure 8: Thickness versus F, F(ANN).

Materials may be compared with each other for a particular sheet metal forming type. Strain hardening exponent is important for stretch forming. R value is accepted as an important forming parameter for deep drawing. However, high values for both R and n at the same time mean good formability whatever the shaping type is. It should be as high as possible, for good deep-drawable materials.

When n values of the tested materials given in Figure 6 are compared, it may be easily seen that the thickest specimen gives the highest value. n values of the specimens have the reverse effects according to R values as shown in Figure 5. In spite of this, when the thickness and the deformation ratio are increased, R values are decreased but n values are increased. It can be said that the low carbon steel specimens have a good deep drawability.

Strain hardening exponent values are found in the range of 1.35-1.96 for steel materials. If these values are compared to n values for the current study, it may be said that the investigated materials are at the good level from earing problem point of view.

Samples were located into the apparatus with a compressing force of 10 kN. The hole diameter of die used is 27 mm. The samples has been lubricated with a grease including graphite in order to produce a thin film before they were located. The experiments were performed at the room temperature. The speed of the spherical tip was taken to be constant during the experiments. For all samples, the height of the cup and the reaction force were determined. The results obtained has been shown in Figure 3,4,7,8.

Data set consists of 6 data for training. In order to make use of data available, the following training method was utilized. Out of 6, 4 patterns were held out as a test file each time. The NN configuration during above process was 1-2-4. That is, 1 nodes in input layer, 2 neurons in hidden layer and 4 neuron in output layer. After training was completed, another data set was prepared for testing. This data set includes 4 patterns. The results regarding with the test file were given in Table 2.

Table 2: Test Results of Trained NN Data.

Pattern	Target	Result	Error
0	1.96	1.90	0.06
1	1.87	1.83	0.03
2	1.81	1.76	0.05
3	1.75	1.73	0.02
4	1.67	1.66	0.01
5	1.40	1.57	0.17
Total	Test	Error %	3.4

3. RESULTS

In this study, deep drawing for 6114 quality of low carbon steel and ANN practicability of the obtained values were investigated. For this purpose, specimens with 0.67-2.0 thickness were subjected to tensile tests and Erichsen test. Also the effect of deformation on the material was investigated. As a result :

1- When the percentage of deformation ratio was increased, R values were decreased and n values were increased (Fig. 1, 2).

2- When the thickness was decreased, R values were decreased but n values were increased (Fig. 5, 6).

3-When the percentage of deformation ratio was increased, h values were decreased and F values were increased (Fig. 3, 4).

4- When the thickness was decreased, h values were decreased but F values were increased (Fig. 7, 8).

5- In spite of limited amount of training data set the generalization capability of NN is fairly acceptable. The test error was less than 3.4 % .

6- In order to improve the estimation ability further with limited amount of data, other type of NN's and learning algorithms such as Radial Basis Function Networks, Probabilistic Neural Networks should be considered.

REFERENCES

1. Dieter, G. E., Mechanical Metallurgy, Mc Graw-Hill London, 1970

2. Savoie, J., Jonas, J. J., "Simulation Of The Deformation Textures Induced by Deep Drawing in Extra Low Carbon Steel Sheets" Acta Metallurgica et Materialia 42, 12 Dec 1994. P. 4101-4116 Publication Year 1994.

3. Kayalı, E. S, Ensari, C, Silahtaroğlu S., "Derin Çekme Kalitesindeki Saçlarda Özellikleri Etkileyen Faktörler" 3. Ulusal Metalürji Kongresi, 1979, ODTÜ., Ankara.

4. Wang, M., Zhang, J., Yu, E., "Formability Of Cold Rolled Dual-Phase Steel Sheet " Kang Tieh/ İron And Steel (Peking) V 28 N 7 Jul 1993. P 37-41 P. Year 1993.

5. Savoie, J., Daniel, D., Jonas, J. J., "Effect Of Deep Drawing On Texture Development in Extra Low Carbon Steel Sheets" Materials Science Forum V 157-6 N Pt 2 1994 . P 1855 - 1860 Publication Year 1994.

6. Çapan, L., "Plastik Şekilverme Teori Ve Uygulamaları" Birsen Kitabevi Yayınları, İstanbul 1984

7. Öztürk, T., "Çelik Saçların Biçimlendirme (Derin Çekme) Özellikleri", Mühendis ve Makina, Cilt 25, Sayı 292, S 12, 1984.

8. Danckert, J., "Experimental Investigation of a Square-Cup Deep Drawing Process" Journal Of Materials Processing Technology, V 50, N 1-4, Mar 1995, p 375 -384.

9. Schepis, R. J., Matlock, D. K., Krauss, G. "Formability Of High Strength Interstitial - Free Sheet " International Symposium on Low-Carbon Steels For The 90's Proc. Int. Symp. Low Carbon Steels, 90, 1993., .Publ. by Minerals, Metals & Materials Soc. (TMS) , Warrendale, PA, USA. P 435-444 P. Year 1993.

10. Savoie, J., Daniel, D., Jonas, J. J., "Textures Induced By Tension and Deep Drawing in Low Carbon And Extra Low Carbon Steel Sheets" Act Metallurgica et Materially, v 41, N 6 Gun 1993, P 1907-1920 Publication Year 1994.

11. Varol, R., Meriç, C., "Comparison of The Formability Of Al 99.0-0, AlMnCu-O Aluminum Alloy Sheets" EMW 94 September 94, Milano, Italy, Eurometal Working 94, P-030-1-7

12. Öztürk, T., Günel, N., Akdeniz, V., Bor, Ş., "Yerli Ve Yabancı Derin Çekme Saçlar Arasinda bir Kıyaslama" 8. Metalürji Kongresi, 1984, ODTÜ, Ankara.

13. Mese, E., "Minimum Permeance Estimation of Variable Reluctance Machines by Using Neural Networks", Mathematical & Computational Applications, Vol. 1, No. 2, pp.87-92, 1996.

14. Haykin, H., "Neural Networks: A Comprehensive Foundation", IEEE Press, Macmillan College Publish. Comp., 1994.