



Investigation of the effects of different chip breaker forms on the cutting forces using artificial neural networks

Hüseyin GÜRBÜZ^{1,*}, Abdullah KURT², Ulvi ŞEKER²

¹*Hacettepe University, Faculty of Engineering, 06800 Beytepe, Ankara/TURKEY*

²*Gazi University, Technology Faculty, 06500 Teknikokullar, Ankara/TURKEY*

Received: 06.01.2012 Resubmitted: 30.04.2012 Accepted: 03.05.2012

ABSTRACT

This paper presents a new approach based on artificial neural networks (ANNs) to determine the effects of different chip breaker forms on cutting forces such as principal cutting force, feed force and passive force, in the machining of AISI 1050. The backpropagation learning algorithm and fermi transfer function were used in the network. The best fitting training data set was obtained with nine neurons in the hidden layer, which made it possible to predict cutting forces with an accuracy which is at least as good as that of the experimental error, over the whole experimental range. After training, it was found that the R^2 values are 0.9829, 0.9667 and 0.9492 for F_C , F_f and F_p , respectively. The average error is %0.145. As seen from the results of mathematical modeling, the calculated cutting forces are obviously within acceptable uncertainties.

Keywords: Cutting forces, Chip breaker form, Artificial neural networks

1. INTRODUCTION

A chip breaker is the small step or groove formed by grinding or the separate part connected to tool holders to break off the chip into short pieces. The obstruction distance behind the cutting edge controls the chip form.

With broader applications of flexible manufacturing systems, computer integrated manufacturing systems, etc., modern technologies using indexable tool inserts with new-style chip breakers are employed widely at the present time. The reliability of machining operations is an essential requirement for modern automatic

manufacturing systems. For turning operations, in which unbroken chips are the major obstacles for the automation, reliability considers chip control as a major aspect.

The initial research on the mechanics of chip in metal cutting was carried out in the second half of the 1900's [1,2]. Different studies were performed by Karahasan [3] in order to evaluate the effect of chip breaking mechanism on cutting. Karahasan used chip breaker forms and manifested the geometrical properties of an optimum chip breaker form to obtain an acceptable chip

geometry. Mesquita and Barata [4] developed a method for predicting cutting forces. In their study, the model considers the indentation or ploughing effect and the presence of a parallel groove type chip breaker. The technique is based on the measurement of the chip breaker geometry and the calculation of the effective side rake angle. The indentation effect, the dynamic shear stress, and the cutting forces were determined from experiments. The proposed model was applied to the machining of martensitic stainless steels using coated carbide tools. The chip breaking performances of the asymmetric groove type (AGT) chip breaker and that of the symmetric groove type (SGT) chip breaker were compared with each other in detail by Fang [5]. The experimental result shows that it is practical to substitute the AGT chip breaker for the SGT breaker and to investigate the rules of chip breaking during machining processes. The influence of the geometrical parameters of the chip groove on the chip breaking performance of the tool insert was investigated through numerous cutting experiments using new style chip breakers. Two mathematical models were suggested to predict the chip breakability for the new style chip breakers using multiple linear regressions. The theoretical predictions were in line with the experimental results under the given cutting conditions. Kim and Kweun [6] modeled the chip flow formation process using different insert geometries and investigated the important characteristic parameters in chip control. The study focuses on the chip breaker design and the experimental cutting of mild steel with the chip breaker. The characteristics of chip breakage for mild steel with respect to the cutting speed, depth of cut and feed rate were analyzed using the experimental results. Das et al. [7] showed that the breaking strain in the chip is the most important factor on which chip breaking depends and a method was suggested for determining the chip breaker distance for any given feed rate and the chip breaker height for effective chip breaking. The method also showed that the chip breaking criterion is based neither on the specific cutting energy nor on the material damage, which can be considered as the adequate criterion for the chip breaking. Mahashar and Murugan [8] performed an experimental work that deal with the influence of two design parameters; the width of chip breaker and the angle of chip breaker of a clamped on chip breaker on effective chip breaking. Artificial neural networks (ANNs) have already been applied to various fields [9-13]. Cardi et al. [14] used ANNs for the detection of chatter vibration in turning; and also Jamali et al. [15] and Nalbant et al. [16] modeled the explosive cutting process by using ANNs. Soleimanimehr et al. [17] used ANNs for the prediction of machining force and the surface roughness in ultrasonic vibration-assisted turning and Szecsi [18] used ANNs to model the cutting force components. Kim et al. [19] evaluated the performance of commercial chip breakers, using a neural network that was trained through the backpropagation algorithm. Important element forms (depth of cut, land, breadth, and radius) that influenced the chip formation directly were chosen among the commercial chip breakers and were employed as input values of the neural network. As a result, Kim et al. [19] developed the performance evaluation method and applied it to commercial tools, which resulted in a significant performance. The chip breaking performance of the tool insert is regarded as one of the most important

factors that maintain the continuity of the machining process. Consequently, it is necessary to investigate the rules of chip breaking systematically and comprehensively when new style chip formers are used. Because of this reason, this subject is interesting for many researchers [20-24].

Cutting forces that occurs during the metal cutting is affected directly from the cutting tool geometry (cutting edge form, nose radius, rake angle, clearance angle and chip breaker form), the cutting tool performance and the cost per product. These forces cause wear, crack, fracture and various deformations on the cutting tool; and they are the basic criteria for machinability. These formations cause the cutting tool function not to be performed. In this condition, the cutting tool is renewed and the cost increases. This is the essential step for the optimum analysis of this process. The measurement of cutting forces is a crucial step in metal cutting for the workbench design, no vibration/rigid machine production and the power required. This paper studies the effects of different chip breaker forms and the cutting parameters such as cutting speed, feed rate and depth of cut on the cutting force components (the principal cutting force, feed force and the passive/radial force) during the machining of AISI 1050. The cutting forces are measured experimentally [25-26].

The progress in neurobiology allowed researchers to build mathematical models based on neurons to simulate the neural behavior. ANN approach has been a well known type of evolutionary computation method in the last decades. ANNs were adapted to a large number of applications in various fields [27-30]. In the field of process engineering, ANNs is a good alternative to the conventional empirical modeling, based on polynomial and linear regressions.

This paper proposes a new approach, to determine the effects of different chip breaker forms on the cutting forces in machining of AISI 1050 with empirical equations based on ANNs. The empirical equations are obtained by ANN using a limited amount experimental data, which is obtained from experimental studies. These equations have a high accuracy.

2. Material and Methods

2.1. Experimental study

Cutting tools and chip breakers: The SNMG 120408R inserts and the PSBNR 2525M12 tool holder that has 75° approaching angle according to the ISO 3685 were used in the experiments. Five groups of chip breaker forms such as STD, MS, GH, SA and MA coated inserts [31] were used in the experiments. These inserts are Mitsubishi grade UC6010 corresponding to the ISO grade P15. Fig. 1 shows the cutting tools. Shape elements of the chip breaker that is sold by Mitsubishi are illustrated in Table 1 and Fig. 1. Although the chip breakability can be determined by diverse elements, in this study, the chip breakability was evaluated with the dimension of elements such as lengths and angles, which are the most important elements that are affected during the chip breaking.

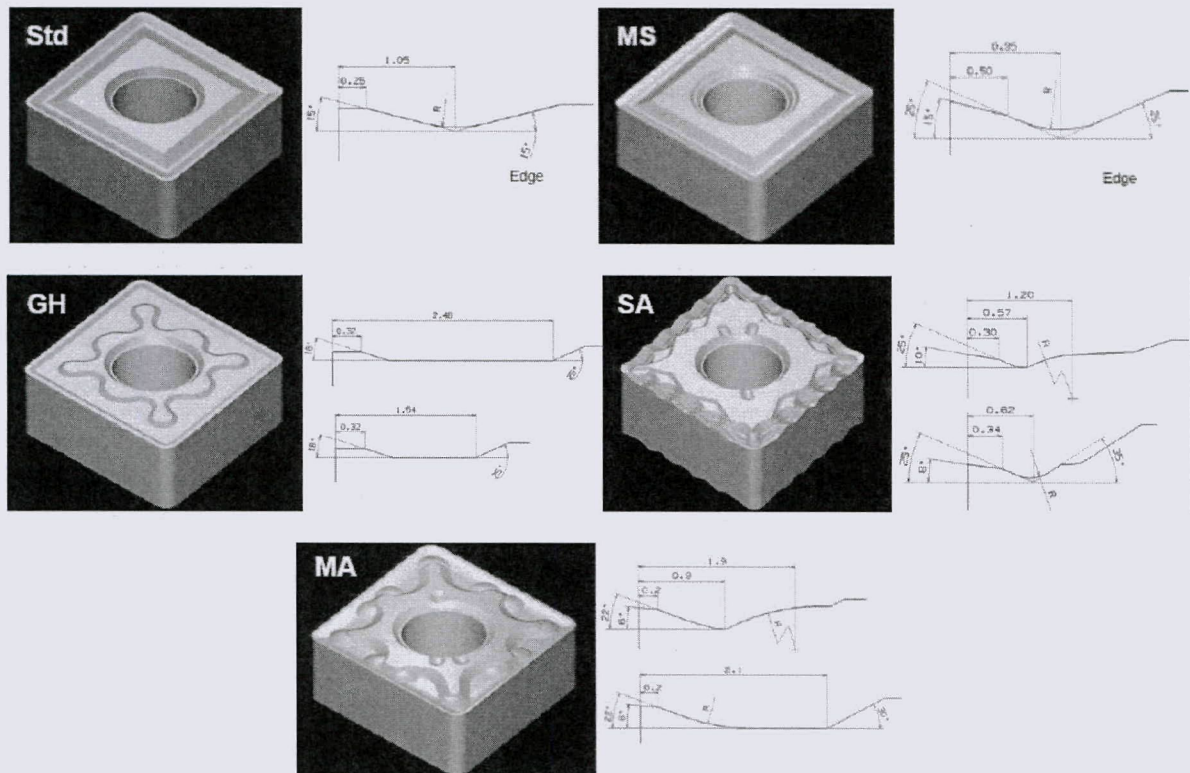


Fig.1. The cutting tools used for the tests and their chip breaker forms [31].

Table 1. Chip breaker could be determined shape elements.

Chip breaker Type	Shape elements (Lengths (l) and Angles (α) for determined chip breaker				
	α_1	l_1	α_2	l_2	α_3
STD	0°	0.25	15°	1.05	15°
MS	15°	0.50	25°	0.95	25°
GH	0°	0.32	18°	2.48	25°
SA	10°	0.30	25°	0.57	35°
MA	6°	0.2	22°	0.9	30°

Cutting parameters and the machine tool: Machining tests were carried out by using five levels of cutting speeds such as 150, 200, 250, 300, 350 m/min, three levels of feed rate such as 0.15, 0.25, 0.35 mm/rev and

two levels of depth of cut such as 1.6, 2.5 mm. The cutting parameters that are used in the experiments are shown in Table 2. JOHNFORD T35 CNC Lathe was used in the tests.

Table 2. Test parameters.

Cutting speed, V (m/min)	Feed rate, f (mm/rev)	Depth of cut, a (mm)
150, 200, 250, 300, 350	0.15, 0.25, 0.35	1.6, 2.5

The Workpiece material and the cutting force measurement: AISI 1050 (DIN 1.1210) workpiece material, which is the most widely used material in the manufacturing industry, was used in the tests. The

chemical composition of AISI 1050 is shown in Table 3. Cutting forces were measured using the KISTLER 9257B dynamometer.

Table 3. The chemical composition of AISI 1050.

%C	%Si	%Mn	%P	%S	%Cr	%Mo	%Ni	%Al	%Co	%Cu	%Fe
0.430	0.212	0.730	0.0197	0.0390	0.0776	0.00752	0.0972	0.0110	0.00603	0.297	98.06

The Test method: 30 tests were carried out for each chip breaker form. A total of 150 experiments were performed with a dry condition. New (unused) inserts were used in each test. The measurement of cutting forces was carried out during the machining. The unvarying/stable cutting force values were determined after all the measurements were performed and the cutting force values for each test were decided.

2.2. Mathematical Modeling: Artificial Neural Network

ANNs are used widely in many application areas such as mathematics, engineering, medicine, economics, etc. ANNs are trained to overcome the limitations of the conventional approaches to solve complex problems. ANN learns from given examples, by constructing an input-output mapping in order to perform predictions [28]. ANNs are practical because of the following reasons [28]:

1. ANNs provide a weighted connection and massively parallel processing with fault tolerance, so that they can automatically learn from experience. This is called internal representation.
2. ANNs have the generalization capability to learn complex patterns of inputs and provide meaningful solutions to problems even when input data contain errors, data are incomplete, or input data are not presented during training. In other words, they have the ability to integrate information from multiple sources and incorporate new features without degrading prior learning.
3. ANNs are distribution free, because no prior knowledge is needed about the statistical distribution of methods that require modeling of the data. Neural networks can avoid some of the shortcomings of statistical and empirical techniques. classes in data sources in order to apply the method for classification. This is an advantage over most statistical and empirical techniques.

4. ANNs can determine how much weight each data source should have in the classification, which remains as a problem in statistical methods. The non-linear learning and smooth interpolation capabilities give the neural network an edge over standard computers and rule-based systems for solving various problems.

Most applications use a feed-forward neural network with the backpropagation training algorithm. The main advantage is that they possess an inherent generalization ability. This means that they can identify and respond to patterns which are similar but not identical to the ones with which they have been trained. A learning algorithm is defined as a procedure that consists of adjusting weights and biases in a network, to minimize an error function between the network outputs, for a given set of inputs, and the correct outputs. There are different learning algorithms. A popular algorithm is the backpropagation algorithm, which has different versions. Backpropagation training algorithms, gradient descent and gradient descent with momentum are too slow for practical problems, because they require small learning rates for a stable learning.

The absolute fraction of variance (R^2) defines the absolute percentage of error, and it is given as follows:

$$R^2 = 1 - \left(\frac{\sum_j (t_j - o_j)^2}{\sum_j (o_j)^2} \right)$$

(1)

The ANN structure is shown in Fig. 2. The Levenberg-Marquardt (LM) algorithm is used in the study. Inputs and outputs are normalized so that they fall in the range (0, 1). Neurons in the input layer do not have a transfer function. Fermi transfer function is used. Products and biases are simply summed, which is followed by transforming through a transfer function to generate a result, and as a result, the output is obtained.

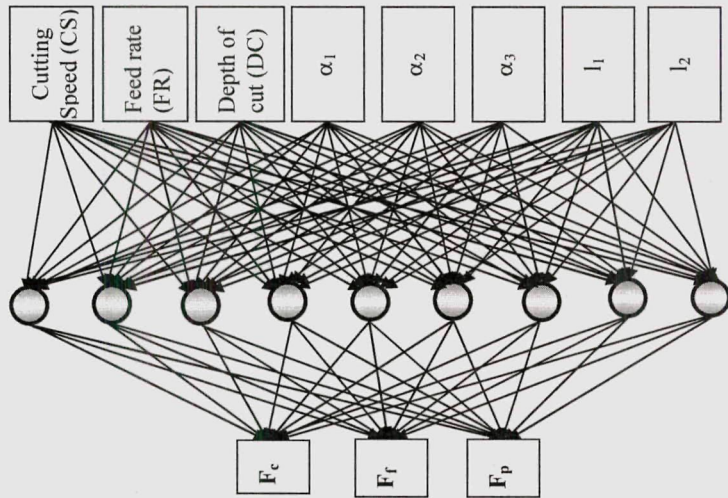


Figure 2. ANN structure.

Five different chip breaker forms are used in the input layer of the network. The cutting forces are in the output layer for all models. The hidden layers have nine neurons. The basic parameters, such as cutting speed, feed rate and depth of cut are considered as an input to the ANN.

3. Results and Discussion

3.1. Experimental Results

The values of cutting force components (principal cutting force, feed force and the passive force; F_c , F_f , F_p , respectively), which are measured by the cutting tests according to different chip breaker forms and variations in the cutting parameters (cutting speed, feed rate and depth of cut) are shown in Fig. 3 to 5. The test results

show that the highest cutting force values are measured on the principal cutting force, feed force and the passive force, respectively. When the graphs in Fig. 3 to 5 are examined, it is seen that the values of the cutting force components (F_c , F_f and F_p) increase with the increase of the depth of cut and the feed rate and decrease with the increase of the cutting speed for all the chip breaker types. This situation is in agreement with the other research [31-34]. Decreasing cutting forces can be explained by increasing energy spent as the cutting speed increases. Almost all of the energy is transformed into temperature. This temperature facilitates the chip formation during machining. According to the following Kienzle's equation; " $F_c = A \cdot k_s$ " cutting forces increase depending on the increase of chip cross-section (A), which is the product of feed rate and depth of cut [35].

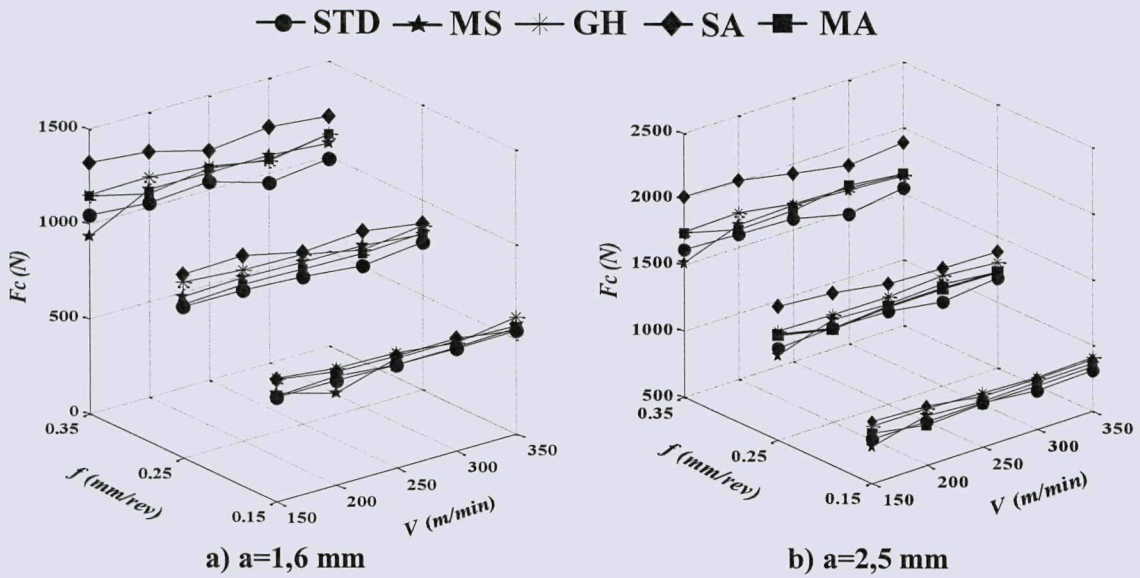


Fig. 3. Variation of primary forces (F_c) depending on chip breaker forms.

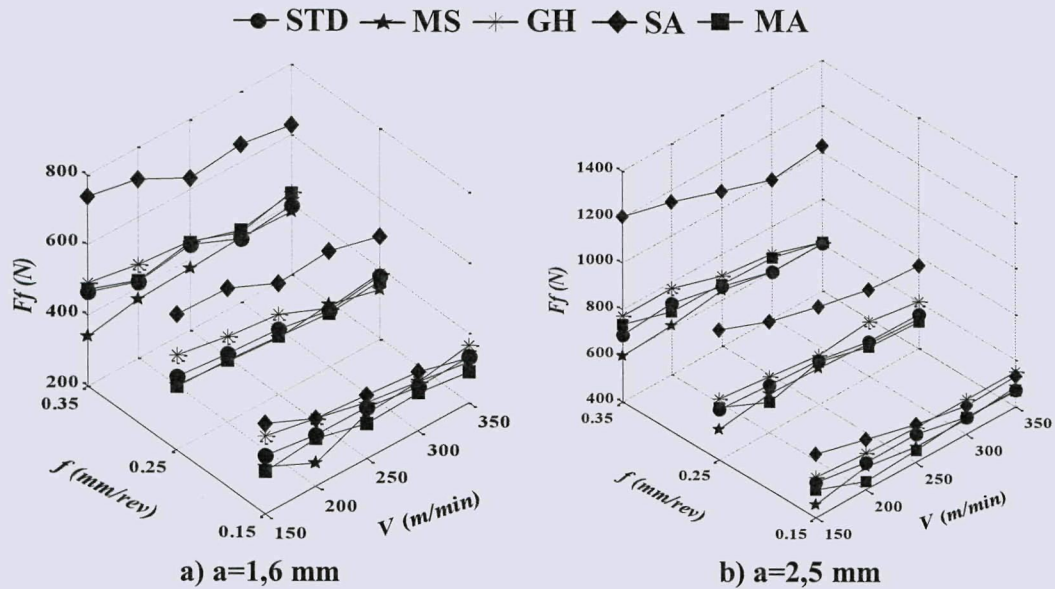


Fig. 4. Variation of feed forces (F_f) depending on chip breaker forms.

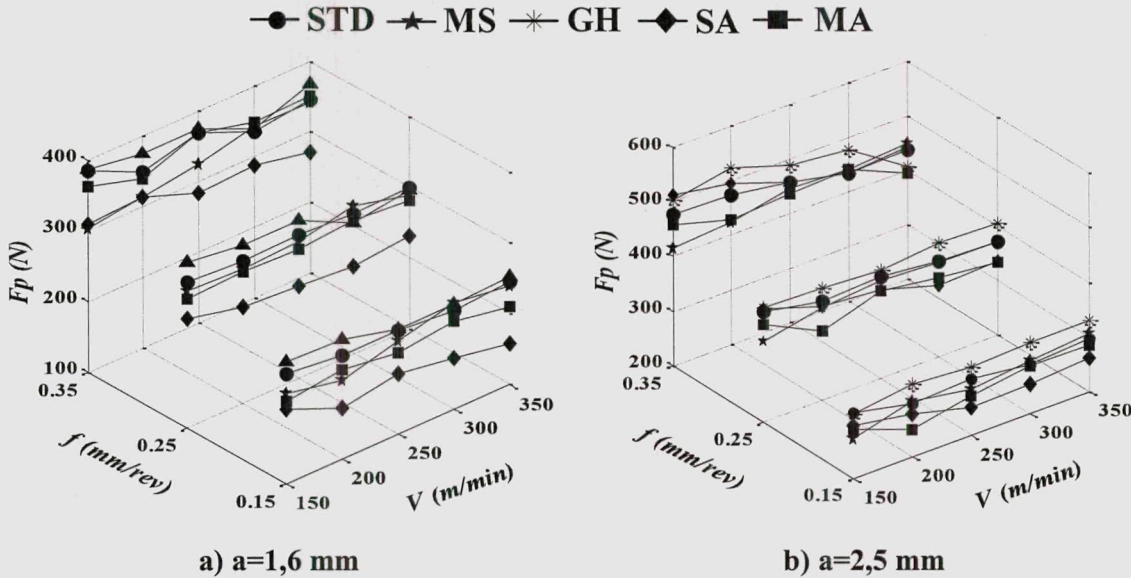


Fig. 5. Variation of passive forces (Fp) depending on chip breaker forms.

Between cutting force components, the principal cutting force has the greatest impact known. From this point if the chip breaker forms are evaluated, the values of highest principal cutting forces on the chip breaker forms SA and GH, the lowest principal cutting forces values on the chip breaker forms STD, MS and MA can be observed. This situation occurred since the manufacturer recommended the light cutting condition for the chip breaker form SA, semi-heavy cutting condition for the

chip breaker form GH and medium cutting condition for chip breaker forms STD, MS and MA. In cutting conditions in which the depths of cut is 2.5 mm and feed rate is 0.35 mm/rev, the highest cutting force component values were measured with the depths of cut is 1.6 mm and the feed rate is 0.15 mm/rev, the lowest cutting force component values were measured for all chip breaker forms.

3.2. Results of the Mathematical Analysis

The new formulations, which are dependent on the main cutting parameters for the outputs, are given with Eqs. 2 - 4. The equations are used for the estimation of

the cutting forces, using different main cutting parameters:

$$F_c = \frac{1}{1 + e^{-4(-0.122732F_1 + 0.493827F_2 + 0.521887F_3 - 0.404305F_4 + 0.333055F_5 - 0.453527F_6 + 0.940058F_7 + 0.743384F_8 - 0.5)}} \tag{2}$$

$$F_f = \frac{1}{1 + e^{-4(0.351140F_1 + 0.057244F_2 + 0.314857F_3 - 0.129994F_4 + 0.417791F_5 - 0.487852F_6 - 1.033940F_7 + 0.514537F_8 - 0.5)}} \tag{3}$$

$$F_p = \frac{1}{1 + e^{-4(0.078695F_1 + 0.421216F_2 + 0.602033F_3 - 0.258552F_4 + 0.796264F_5 - 0.796155F_6 - 2.068409F_7 + 0.326063F_8 - 0.5)}} \tag{4}$$

where; F_i ($i=1,2,...,8$) can be calculated by the fermi function according to Eq.5. The formulation for the prediction of the cutting forces (Eqs. 2 to 4), which are

dependent on the cutting parameters, are given with Eq. 6. In Eq. 5, E_i ($i=1,2,...,9$) is given with Eq. 6, which is based on the main cutting parameters.

$$F_i = \frac{1}{1 + e^{-4(E_i - 0.5)}} \tag{5}$$

$$E_i = C_{1i} * \alpha_1 + C_{2i} * l_1 + C_{3i} * \alpha_2 + C_{4i} * l_2 + C_{5i} * \alpha_3 + C_{6i} * CS + C_{7i} * FR + C_{8i} * DC \tag{6}$$

The constants (C_{ij}) in Eq.6 are given in Table 4.

Table 4. Constants in Eq.6

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9
C_{1i}	-0.476620	-0.559270	-0.587898	0.175976	-1.210561	-0.796399	1.825169	-2.724624	1.431483
C_{2i}	0.929563	0.716396	-2.136200	1.483085	-0.880276	-2.931872	-1.962083	2.351739	-1.958817
C_{3i}	-1.027395	0.045802	-0.713339	-1.468852	-0.715532	-0.231816	0.972018	-1.880695	0.048784
C_{4i}	-7.131836	-0.357313	0.615304	-0.165433	-8.204341	-1.548001	1.555212	-1.902957	0.257463
C_{5i}	1.118563	-0.007316	1.284926	-0.141403	-0.157377	-2.147223	-2.259936	2.506062	0.190066
C_{6i}	-0.132383	-0.158886	-0.039975	-1.271354	-0.119264	-0.389275	0.062223	-0.927386	0.111294
C_{7i}	1.288653	1.393166	-0.321403	0.173557	1.497301	0.755749	-0.484406	0.465857	-3.047957

To be used in training data, Figs. 6-8 present the ANN performance of the determination of cutting forces for each force, respectively. In general perspective, according to the results obtained, the deviation of cutting

forces between the measurement and the prediction of a ANN is negligible in the range of $\pm 0.4\%$ (Figs. 9-13) for different chip breaker forms.

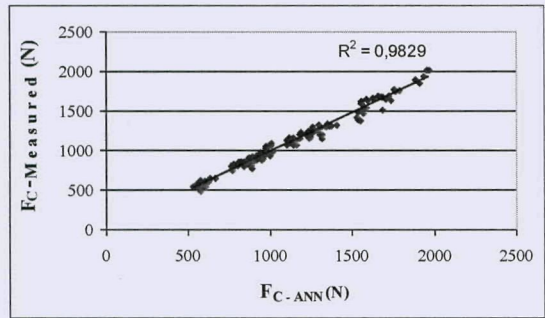


Fig.6. Comparison of the $F_{c\text{-measured}}$ data and $F_{c\text{-ANN}}$

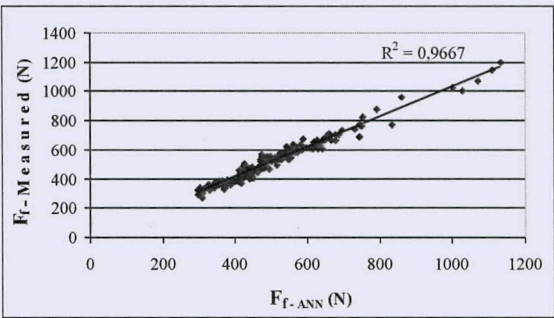


Fig.7. Comparison of the $F_{f\text{-measured}}$ data and $F_{f\text{-ANN}}$

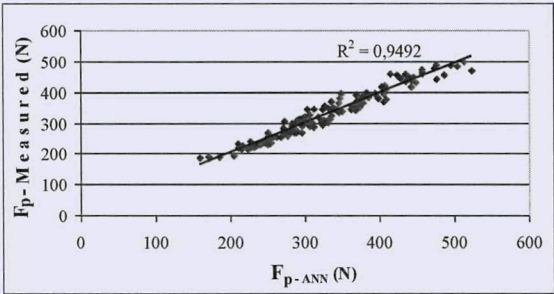


Fig.8. Comparison of the $F_{p\text{-measured}}$ data and $F_{p\text{-ANN}}$

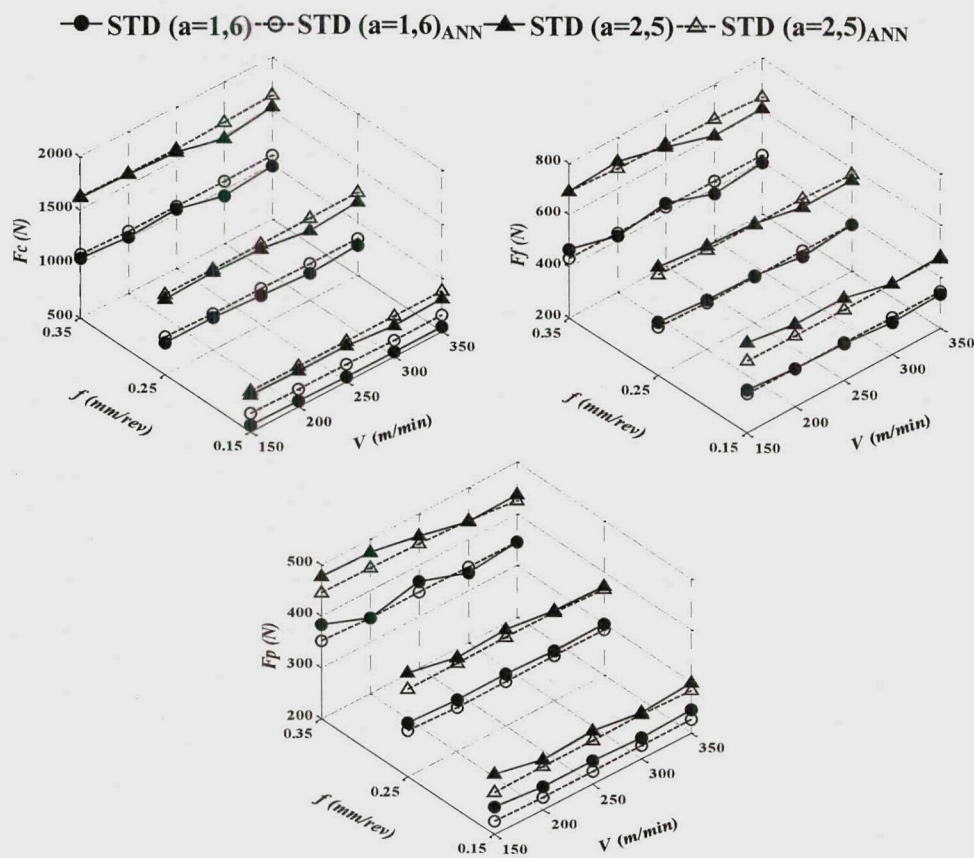


Fig. 9. The performance of ANN (chip breaker forms STD).

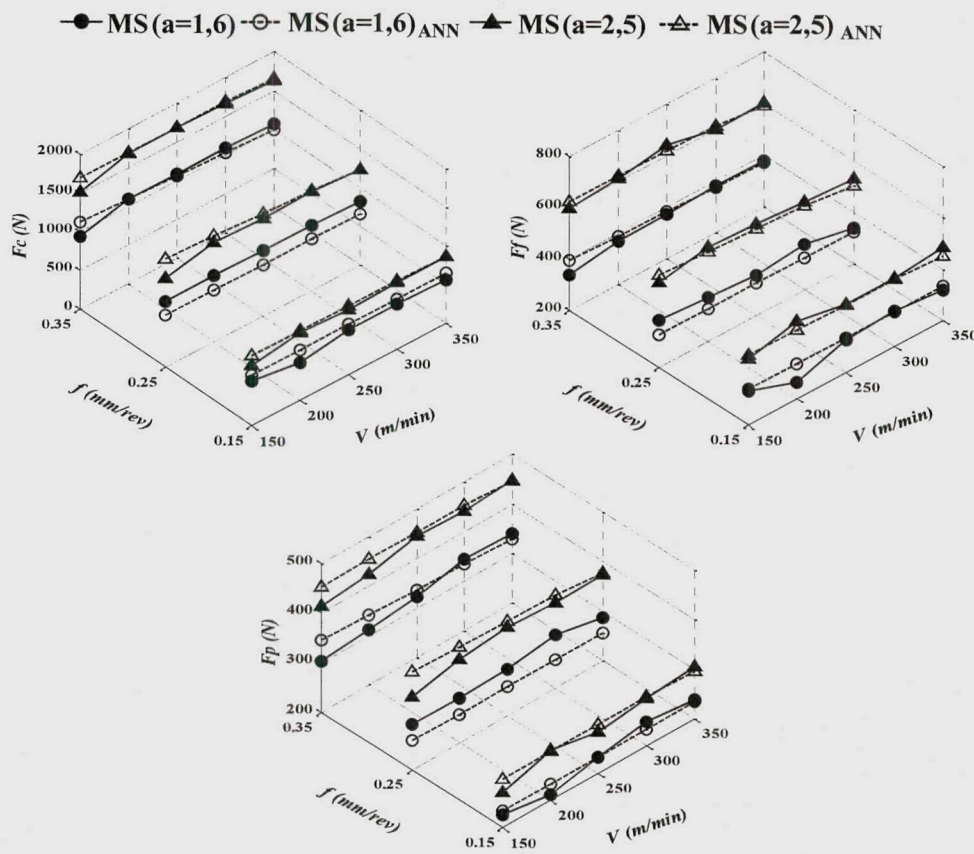
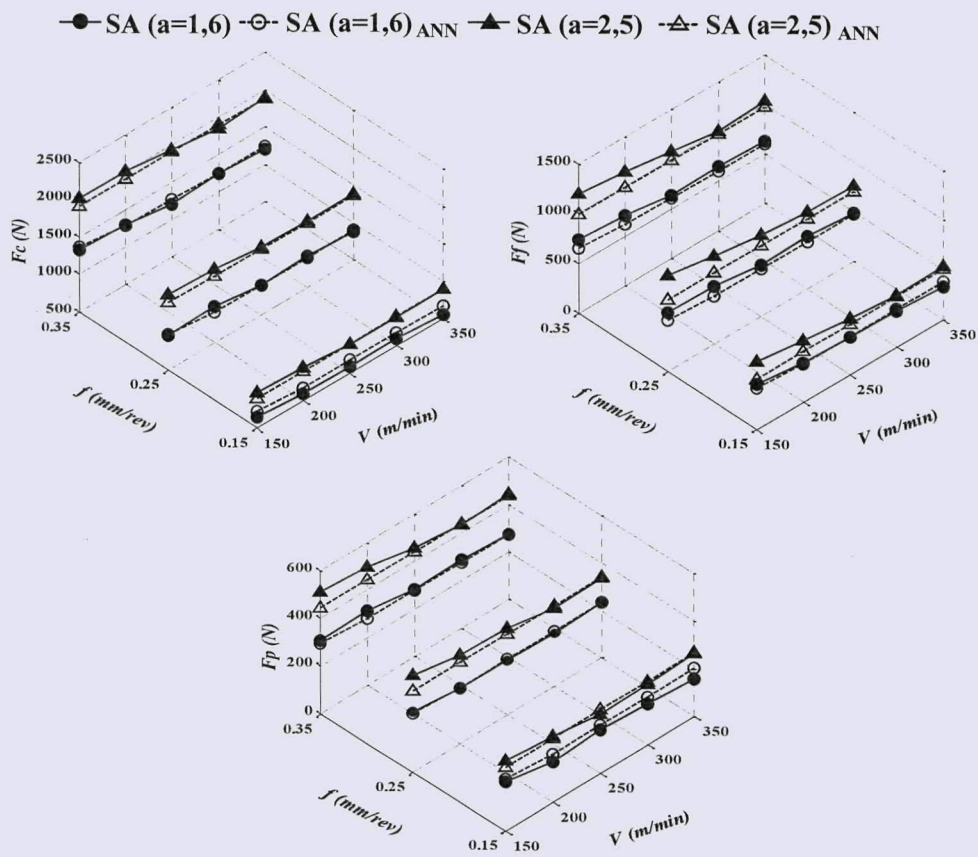
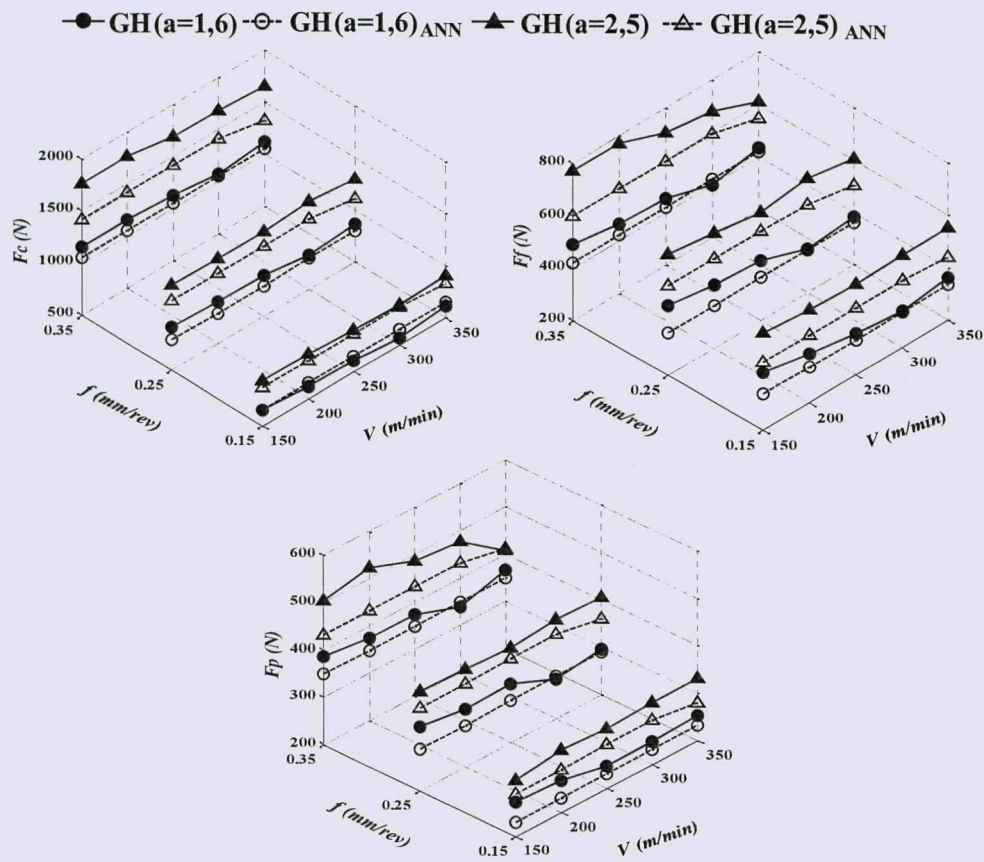


Fig. 10. The performance of ANN (chip breaker forms MS).



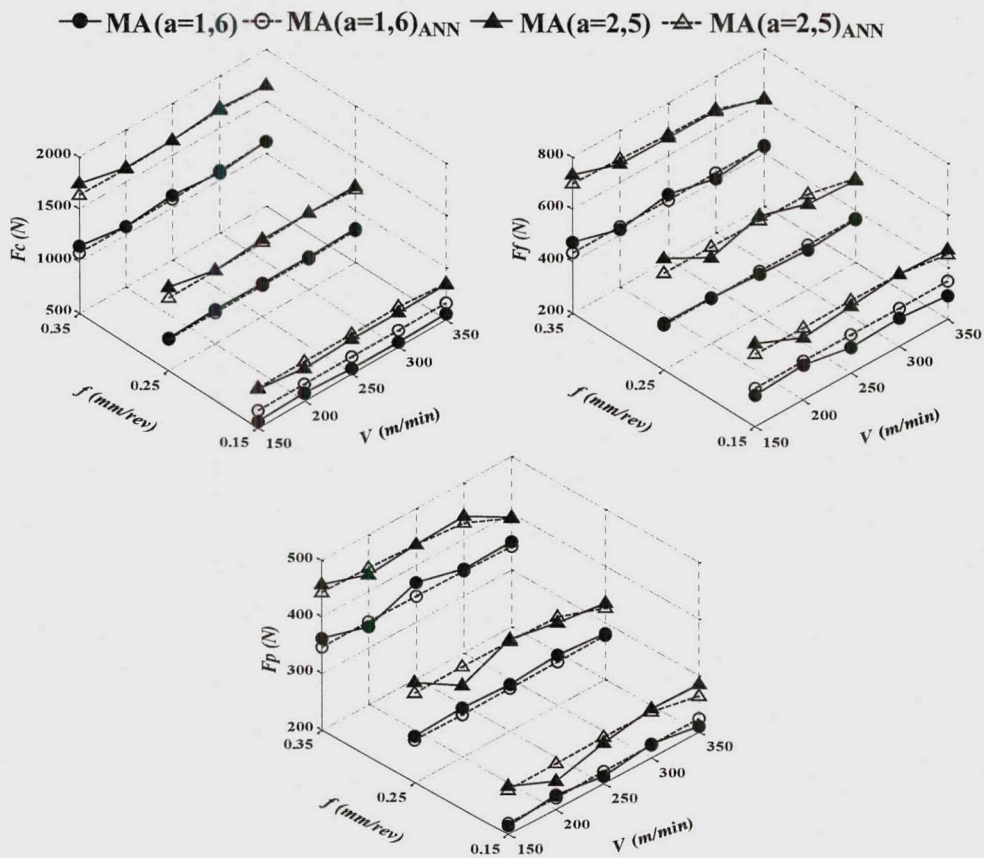


Fig. 13. The performance of ANN (chip breaker forms MA).

4. Conclusions

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

- The test results show that the highest cutting forces values are measured on the principal cutting force (F_c), the feed force (F_f) and the passive force (F_p), respectively.
- Generally, the cutting force component (F_c , F_f and F_p) values increase when depth of cut and feed rate increases and decrease when cutting speed increases for all the chip breaker types.
- The highest values of the principal cutting forces on the chip breaker forms SA and GH, the lowest values of the principal cutting forces on the chip breaker forms STD, MS and MA are observed.
- In cutting conditions in which the depth of cut is 2,5 mm and feed rate is 0,35 mm/rev, the highest cutting force component values and in cutting conditions in which the depth of cut is 1,6 mm and feed rate is 0,15 mm/rev, the lowest cutting force component values were measured for all chip breaker forms.
- The results of the validation and the comparative study indicate that the ANN based estimation technique for the cutting force component is appropriate.
- Developed chip breaker forms tested with ANN were applied to a commercial cutting tool with different chip breaker forms and in various cutting conditions to predict the cutting force components.

Acknowledgements

The authors thank to Gazi University for providing financial support for the project (Project Code: 07/2005–01). Also, the author would like to thank Prof. Dr. Adnan SÖZEN for critically reviewing the original manuscript and application of ANN.

References

- [1] Cook, N.H., Jehaveri, P., "The mechanism of chip curl and its importance in metal cutting", *Trans.*, 85(B): 374- 380 (1963).
- [2] Spaans, C., Geel, P.F.H.J., "Breaking mechanisms in cutting with a chip breaker", *Ann. CIRP*, 18: 87-92 (1966).
- [3] Karahasan, Z.O. The Influences of tool geometry and chip breaker form of cutting on tool performance, MSc. Thesis (in Turkish), Yıldız Technical University, Science and Technology, Istanbul, Turkey, pp.153-161 (1995).
- [4] Mesquita, R.M.D., Barata Marques, M.J.M., "Effect of chip-breaker geometries on cutting forces", *J. Mater. Pro. Tech.*, 31: 317-325 (1992).
- [5] Fang, N., "Influence of the geometrical parameters of the chip groove on chip breaking performance using new-style chip formers", *J. Mater. Pro. Tech.*, 74: 268-275 (1998).

- [6] Kim, J.D., Kweun, O.B., "A chip-breaking system for mild steel in turning", *Int. J. Mach. Tools and Manuf.*, 37: 607-617 (1997).
- [7] Das, N.S., Chawla B.S., Biswas C.K., "An analysis of strain in chip breaking using slip-line field theory with adhesion friction at chip/tool interface", *Journal of Materials Processing Technology*, 170: 509-515 (2005).
- [8] Mahashar, A. J. Murugan M., "Influence of chip breaker location and angle on chip form in turning low carbon steel", *International journal of machining and machinability of materials A*, 5(4): 452-475 (2009).
- [9] Zuperl, U., Cus, F., Mursec, B., and Ploj, T., "A hybrid analytical-neural network approach to the determination of optimal cutting conditions", *Journal of Materials Processing Technology*, 157-158: 82-90 (2004).
- [10] Ezugwua, E. O., Fadarea, D. A., Bonney, J., Da Silva, R. B. and Sales, W. F., "Modelling the correlation between cutting and process parameters in high-speed machining of Inconel 718 alloy using an artificial neural network", *International Journal of Machine Tools & Manufacture*, 45: 1375-1385 (2005).
- [11] Karayel, D., "Prediction and control of surface roughness in CNC lathe using artificial neural network", *Journal of Materials Processing Technology*, 209: 3125-3137 (2009).
- [12] Paulo Davim, J., Gaitondeb, V.N., and Karnik, S.R., "Investigations into the effect of cutting conditions on surface roughness in turning of free machining steel by ANN models", *Journal of Materials Processing Technology*, 205: 16-23 (2008).
- [13] Kurt, A., "Modelling of the cutting tool stresses in machining of Inconel 718 using artificial neural networks", *Expert Systems with Applications*, 36: 9645-9657 (2009).
- [14] Adam, A. Cardi, Hiram A. Firpi, Matthew T. Bement, and Steven Y. L., "Workpiece dynamic analysis and prediction during chatter of turning process", *Mechanical Systems and Signal Processing*, 22: 1481-1494 (2008).
- [15] Jamali, A., Nariman-zadeh, N., Darvizeh, A., Masoumi, A., and Hamrang, S., "Multi-objective evolutionary optimization of polynomial neural networks for modelling and prediction of explosive cutting process", *Engineering Applications of Artificial Intelligence*, 22: 676-687 (2009).
- [16] Nalbant, M., Gökkaya, H., Toktaş, İ., Sur, G., "The experimental investigation of the effects of uncoated, PVD-and CVD-coated cemented carbide inserts and cutting parameters on surface roughness in CNC turning and its prediction using artificial neural Networks", *Robotics and Computer-Integrated Manufacturing*, 25: 211-223 (2009).
- [17] Soleimanimehr, H., Nategh, M. J. and Amini, S., "Prediction of machining force and surface roughness in ultrasonic vibration-assisted turning using neural networks", *Advanced Materials Research*, 83-86: 326-334 (2010).
- [18] Szecsi, T., "Cutting force modeling using artificial neural networks", *Journal of Materials Processing Technology*, 92-93: 344-349 (1999).
- [19] Kim H.G., Sim J.H., Kweon H.J., "Performance evaluation of chip breaker utilizing neural network", *Journal of Materials Processing Technology A*, 209(2): 647-656 (2009).
- [20] Jiang, C.Y., Zhang, Y.Z. and Chi, Z.J., "Experimental research of the chip flow direction and its application to the chip control", *Ann. CIRP*, 33: 81-84 (1984).
- [21] Komanduri, R. and Brown, R.H., "On the mechanics of chip segmentation in machining", *Transactions of American Society of Mechanical Engineers Journal of Engineering for Industry*, 103: 33-51 (1981).
- [22] Jawahir, I.S. and Luttervelt, C.A.V., "Recent Developments in Chip Control Research and applications", *Annals of the CIRP*, 42(2): 659-693 (1993).
- [23] Jawahir, I.S., Qureshi, N. and Arsecularatne, J.A., "On the interrelationships of some machinability parameters in finish turning with cermet chip forming tool inserts", *Int. J. Mach. Tools Manuf.*, 32: 709-723 (1992).
- [24] Fang, X.D., Fei, J. and Jawahir, I.S., "A Hybrid Algorithm for Predicting Chip Form/Chip Breakability in Machining", *Int. J. Mach. Tools Manuf.*, 36(10): 1093-1107 (1996).
- [25] Gürbüz, H., The Effect on The Cutting Tool Stresses of The Different Chip Breaker Form in Turning, MSc. Thesis (in Turkish), Gazi University, Institute of Science and Technology, Ankara, Turkey, (2006).
- [26] Gürbüz, H., Kurt, A., Korkut, İ., Şeker, U., "The experimental investigation of the effects of different chip breaker forms on the cutting forces", *Advanced Materials Research*, 23: 191-194 (2007).
- [27] Kalogirou, S.A., "Artificial intelligence for the modeling and control of combustion processes: a review", *Progress in Energy and Combustion Science*, 29: 515-566 (2003).
- [28] Sozen, A., "Future projection of the energy dependency of Turkey using artificial neural network", *Energy Policy*, 37(11): 4827-4833 (2009).
- [29] Karataş, C., Sozen, A., Dulek, E., "Modelling of residual stresses in the shot peened material C-1020 by artificial neural network", *Expert Systems with Applications*, 36(2): 3514-3521 (2009).
- [30] Sözen, A., Arcaklioğlu, E., Menlik, T., Ozalp, M., "Determination of thermodynamic properties of an alternative refrigerant (R407c) using artificial neural network", *Expert Systems with Applications*, 36(3): 4346-4356 (2009).
- [31] Mitsubishi Carbide, Turning Tools, Rotating Tools, Tooling Solutions, General Catalogue, (2005).
- [32] Chen, W., "Cutting Forces and Surface Finish When Machining Medium Hardness Steel Using CBN Tools", *International Journal of Machine Tools & Manufacture*, 40: 455-466 (2000).

- [33] Trent, E.M., Metal Cutting, Butterworths Press, 1-171, London, (1989).
- [34] Zhao, J., Ai X. and Li, Z., "Finite element analysis of cutting forces in high speed machining", *Materials Science Forum*, 532-533: 753-756 (2006).
- [35] Seker, U., Lecture notes in Tool design (in Turkish), Gazi University, Technical Education Faculty, Ankara, Turkey, pp. 33-44, pp.47-72 (1997).

Copyright of Gazi University Journal of Science is the property of Gazi University Journal of Science and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.