Indian Journal of Engineering & Materials Sciences
Vol. 24, April 2017, pp. 115-122

Examination of the effects of burnishing apparatus on surface roughness and hardness in burnishing process

Hudayim Basak[a]* & Fikret Sonmez[b]

[a]Faculty of Technology, [b]Graduate School of Natural and Applied Sciences,
Gazi University, Besevler, 06500 Ankara, Turkey

Received 14 September 2015; accepted 10 February 2017

Burnishing process is a finalization process used to improve the quality of the surface. The advantages of this process is to increase surface hardness and decrease of surface roughness on the surface work-piece on which it is applied, resistance against material fatigue and abrasion resistance. In this study, the design and manufacture of three different apparatus has been realized in order to perform burnishing process by using different parameters (burnishing force, feed rate and number of passes). The effects of these parameters on the Al-6061-T6 material have been examined depending on surface hardness and surface roughness. The test results obtained by the apparatus used in the study are compared with each other. Also the effects of parameters used during burnishing on surface roughness and surface hardness are determined. Finally, the obtained results have been assessed on artificial neural networks (ANN) by using different neuron structures and algorithms, and the obtained data are compared with the test results.

Keywords: Burnishing process, Surface roughness, Surface hardness, Artificial neural networks

The burnishing process is a cold formation process realized by crushing the surfaces of materials without machining. Burnishing process involves decrease in surface roughness, increase in surface hardness and improvement in residual stress.[1] A typical example of burnishing process is shown in Fig. 1. In this example, it is being observed that the characteristics of the surface improve by providing the required pressure in order to create deformation on surface layer through ball burnishing or roller burnishing.[2]

In Fig. 1, *P* is the burnishing force (burnishing pressure, tool pressure force), *f* the feed, *n* the rotational speed, *Rz* the surface roughness before burnishing, Rz_b the surface roughness after burnishing, r_d the radius of tool tip rounding, *u* the tool indentation, RS_m is the mean spacing of profile irregularities before burnishing.[2]

In this finishing operation technique, it can be used in mechanical improvement processes and in geometrical improvement processes among removing the out-of-roundness.[3] The burnishing process is affected by some parameters such as the crushing material, revolution of burnishing, feed rate, number of passes and burnishing force.[1-16] While performing burnishing process, the use of lubrication assists the improvement of mechanical features and avoid heat generation or adhesion problems.[4-10] In order to optimize the surface improvement, it can also be used with processes such as cryogenic pre-cooling[11], ball polishing[12], ultrasonic finishing[7] and electrochemical finishing[13] among secondary processes. Majority of experimental studies have been performed with soft materials excluding iron such as aluminum and brass. But the burnishing process allows the implementation polymers[10], for non-ferrous metals[3,8], soft steels[1] and hard steels[4,11] in respect of capacity. This significant finishing operation can also be made by using universal milling machine and universal lathe as well as easily made on CNC machines, and thus it is

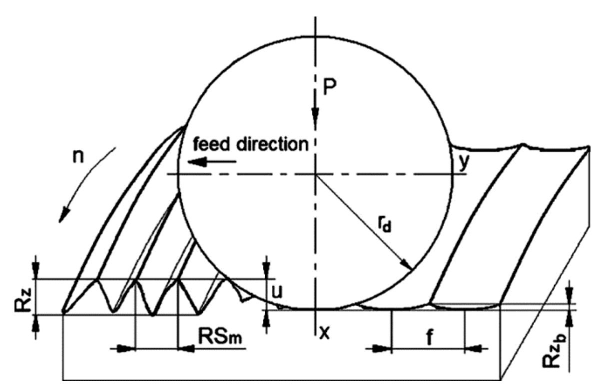

Fig. 1 — Burnishing process[2]

*Corresponding author (E-mail: hbasak@gazi.edu.tr) having a wide implementation area. The burnishing process is being performed either by balls or rollers in order to crush the Surface.[1-16] Along with this, spring-based pressure[1], hydraulic pressure[10] are also used to obtain required pressure.

Researchers study with models to understand the influence of different burnishing parameters. Effect of the parameters investigate with mathematical models[2] and optimization technique namely fuzzy logic[8,14] and artificial neural networks (ANN).[15,16]

The aim of this study is to examine the effects of burnishing parameters such as pressure force, feed rate and number of passes on burnishing in three different burnishing apparatus having different pressure caps (ball revolving and double revolving). Moreover, the assessment of the most suitable apparatus had also been made by comparing the apparatus. In order to search for the interrelations of burnishing parameters and to examine the analyzability of results, the obtained experimental results had been assessed by artificial neural networks. In this assessment, the applicability of training algorithms in the solution of this problem had been searched by assessing the fault rates obtained in three different training algorithms.

Experimental Study

For the experimental study, the design and manufacture of apparatus which can be used in the burnishing of rotating parts and which can be attached to the tool post section of the lathe has been performed. Three different caps which can be attached to a single body have been used in the design of apparatus (Fig. 2). The caps used for the burnishing process are designed as ball, roller and double roller apparatus. The manufacture of apparatuses has been performed with AISI 1060 material through machining, and the parts with crushing feature are manufactured with AISI 316 and 100Cr6 materials, and the roughness value is decreased to 0.15 μm. The apparatus ends, acquired as ready-made and used as crusher, has a roughness value of 0.15 μm as catalogue value.

In this study, work-pieces of Al-6061 T6 aluminum alloy had been used. The material was received in the form of bars, external diameter of 20 mm and length of 150 mm. Specimen external diameter machined into 18 mm. Average material hardness of the experiment's material is measured as 139.2 Brinell (HB30), and its average surface roughness is measured as *Ra* 3.2. The chemical structure of Al-6061 T6 material used in the experiments is shown in Table 1.

In the burnishing study, four different parameters as being pressure force, feed rate, number of passes and type of apparatus had been shown in Table 2.

In order to better see the effect of parameters as independently, the burnishing process has been performed by only changing one of the values seen on the table in each experiment. A total of 36

Table 1 — Chemical composition of Al 6061 –T6

Al	Mg	Si	Fe	Cu	Cr	Zn	Mn	Ni	Ti
97.92%	1.00%	0.65%	0.35%	0.30%	0.23%	0.08%	0.05%	0.05%	0.04%

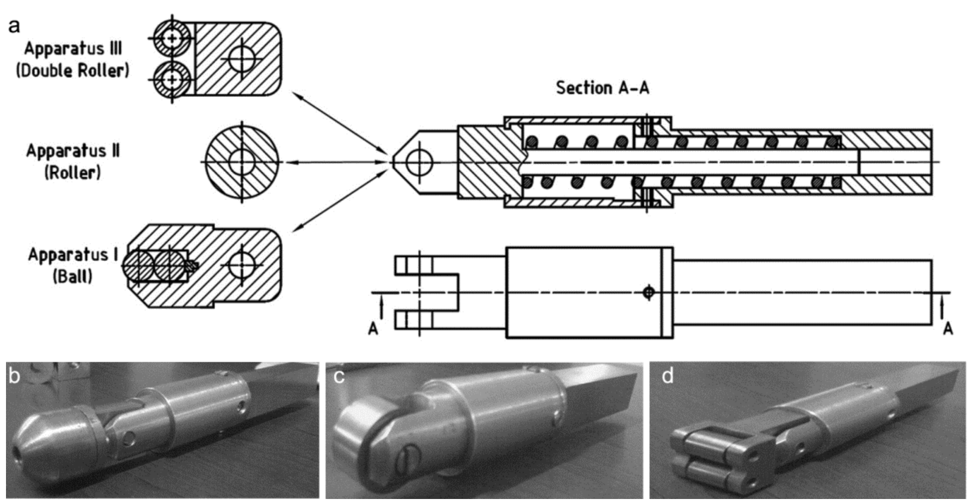

Fig. 2 — (a) Types of apparatus, (b) ball, (c) roller and (d) double roller

experiments have been performed for each of the three different apparatus being manufactured, and 108 experiment results are obtained in total.

The pressure force required for the performance of burnishing process is obtained by spring pressure. Thus, different pressure forces are obtained at different spring tightening rates. After connecting the burnishing apparatus to universal lathe, it is ensured for the spring to generate pressure by providing feed from the bench top. For all the experiments, the work-piece has been put between the chuck and tailstock and the processes are performed with a fixed speed of 500 rpm. The experiments are conducted without coolant. In Fig. 3, the connection of experiment's apparatus to lathe and performance of burnishing process on the experiment's sample are being seen.

Table 2 — Parameters used in the study

Burnishing force (N)	30—50—65—80
Feed rate (mm/rev)	0.12—0.24—0.36
Number of passes	1—2—3
Type of apparatus	Apparatus I – Apparatus II – Apparatus III

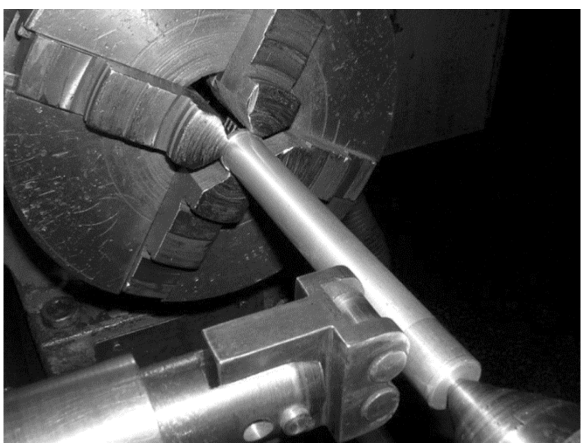

Fig. 3 — Burnishing mechanism

Results and Discussion

As the result of the experiments, the work-pieces is measured by Mitutoyo Surftest SJ-201 surface roughness measurement device and Digirock-Rbov surface hardness measurement device, and these measurements are entered on the cards of experiment's samples. Three measurements have been made for each work-piece, and average values are determined.

The surface roughness values of apparatuses obtained during the experiments is shown in Fig. 4.[17] When the graph is examined, it is being observed that all apparatuses have positive effect in decreasing the surface roughness and that all apparatuses have improved the surface roughness and directed its value under *Ra* 3.2 being the raw value.

In the case of best improvement, the surface roughness is realized at the level of 0.423 µm, and this result is obtained by ball apparatus (Apparatus I). And the lowest surface improvement is obtained by the double roller apparatus (Apparatus III) with a roughness value of 2.643 µm. In the experiments performed, it has been observed that the improvement of surface roughness is realized in the range of 21% - 750%. In the results obtained from the apparatuses, a relation can be established in between the contact surfaces of apparatuses and the surface roughness. In the graphs, it is being observed that the force affecting the work-piece on the contact surface decreases by the widening of contact area of apparatus, and as a consequence that less plastic deformation occurs in apparatuses with wide surface. It is also being thought that this condition is a result relevant to magnitude of pressure force applied during burnishing. It is being considered that the pressure forces used in this experiment set has caused such a result. In case of increasing the applied pressure force, it is being estimated that apparatuses with wide

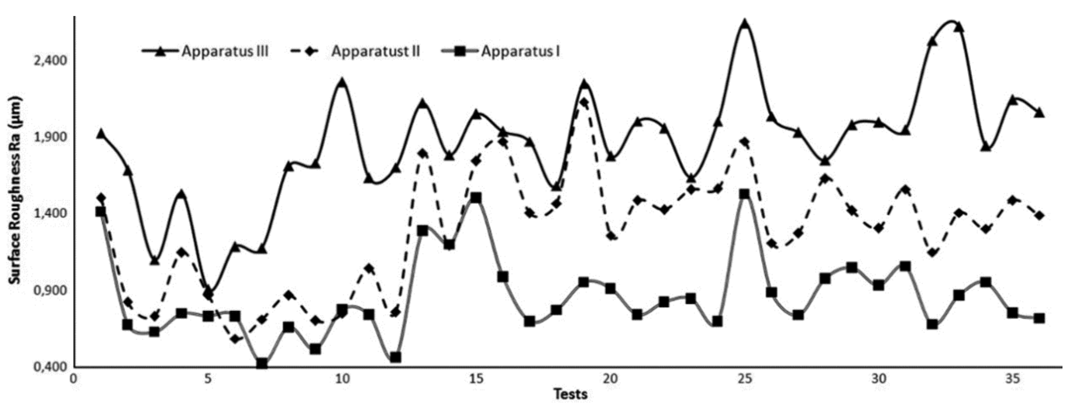

Fig. 4 — Effects of apparatus on surface roughness[17]

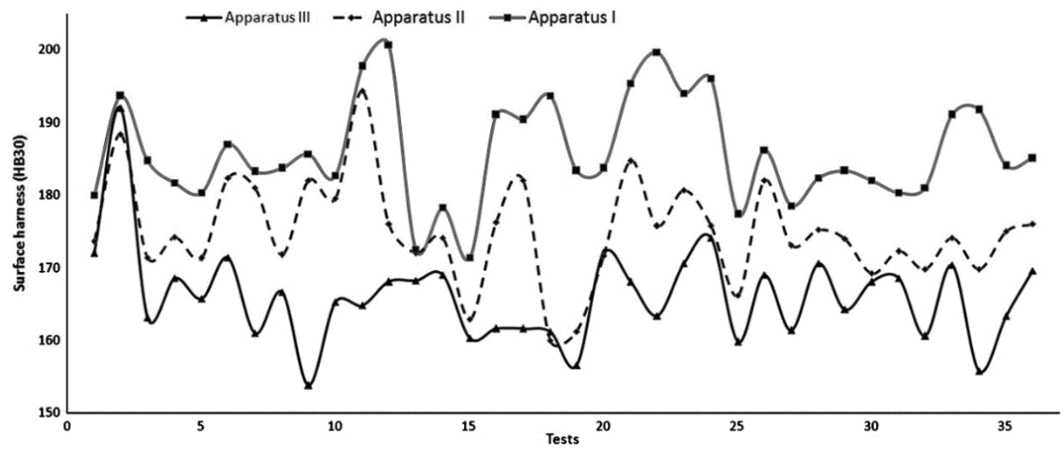

Fig. 5 — Effects of apparatus on surface hardness[17]

surface may provide better results in respect of surface roughness[17].

When Fig. 5 indicating the surface hardness values is analyzed, it is observed that the surface hardness value is being directed over 139.2 Brinell (HB30) being the raw value after the experiments made by all the apparatuses[17].

The highest surface hardness is measured as 200.67 Brinell (HB30) on the ball apparatus, and the surface hardness is increased by 45%. The apparatuses are lined up similar to surface roughness graph. Apparatus have different crushing surface areas. The pressure force applied under the current experimental conditions has caused different immersion depths due to surface areas. The crushing ends of the apparatus with wide surface has immersed less on the work-piece, and this condition has caused the surface of work-piece to be crushed less. Thus, while having the best surface hardness values with the ball end apparatus, the roller apparatus and double roller apparatus have followed the ball apparatus respectively. Both in respect of surface hardness and surface roughness, ball apparatus has enabled better results[17].

Examination of effects of experiment's parameters

In this section, the effects of variables of feed rate, burnishing force and number of passes being the experiment's parameters on the surface roughness and surface hardness have been examined. Dispersion graphs has been composed on the Minitab 16[18] program by the data obtained as the results of experiments performed by using three types of apparatus and different experiment parameters (feed rate, number of passes and burnishing pressure force), and the effects of parameters used in the experiment set on the surface roughness and surface hardness are examined.

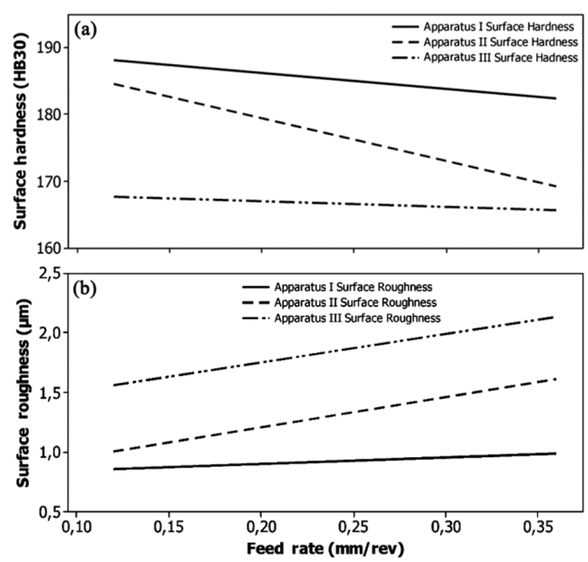

Fig. 6 — General effect of the change of burnishing feed rate on (a) surface hardness and (b) surface roughness (Apparatus I: Ball, Apparatus II: Roller, Apparatus III: Double Roller)

Effects of feed rate on surface hardness and surface roughness

In literature, it is being explained that the increase of feed rate causes decrease in surface hardness and deterioration in surface roughness.[1,4] It can also be said by the experimental results of this study that surface hardness is decreased and surface roughness value is increased by the increase of feed rate.

In the experiments performed by changing only one variable in each experiment set, it is observed that there exists an inversely proportional relation in between feed rate and surface hardness (Fig. 6a). In this case, it can be said that the increase of feed rate causes less crushing of surface layer and better surface hardness values can be obtained by lower feed rates. The increase of feed rate has negatively affected the surface hardness, and this condition is observed in the same manner on all three apparatuses.

It is observed from Fig. 6b that surface roughness value has negatively been affected from the change in feed rate. When the relation of feed rate and surface roughness is examined, it is observed that lower feed rate values has provided better roughness values. This condition implies that the piece crushes more at lower feed rates and that micro peaks and pits on the surface of piece decreases.

Effect of number of passes on surface hardness and surface roughness

When the literature is examined, it is understood that the increase of number of passes have a positive effect on surface hardness and surface roughness.[1,4] The data obtained in the present study match with results reported in the literature. It is observed from the obtained graphs that the increase of number of passes have a positive effect on surface hardness (Fig. 7a). In this study, as well as observing the positive effect of number of passes, it is thought that the reason of lack in realization of this effect at the required level is relevant to other parameters being used and especially the pressure force. The positive effect of number of passes on surface hardness and surface roughness will increase by increasing the pressure force. In the same manner, it can be said from the obtained graphs that increase of number of passes have a positive effect on surface roughness (Fig. 7b). The change in the number of passes provides limited contribution to surface improvement. In the current experimental conditions, number of passes reflects the limited improvement on the contrary the literature.[1-3]

Effects of burnishing force on surface hardness and surface roughness

In literature, when the relation of burnishing force and surface hardness and surface roughness is examined, it is specified that the increase of burnishing force has positive effect on surface hardness and surface roughness.[1,4] Data matching with the literature knowledge have also been obtained in the studies performed. It is observed from the obtained graphs that the increase of burnishing force have a positive effect on surface hardness (Fig. 8a). But this effect is less than expected under the conditions of present experiment. It is observed from (Fig. 8b) that the increase of burnishing force have a positive effect on surface roughness. The low degree of pressure force used in the conditions of the experiment has caused this change to remain at degrees lower than expected. The amount of change may increase in case of increasing the pressure force.

When the results of experiment are assessed in respect of the parameters used in the experiment, it is observed that while the increase of feed rate negatively affects the surface roughness and surface hardness, the increase of pressure force and number of passes positively affect the surface roughness. The obtained results are in agreement with the reported results.[3,4]

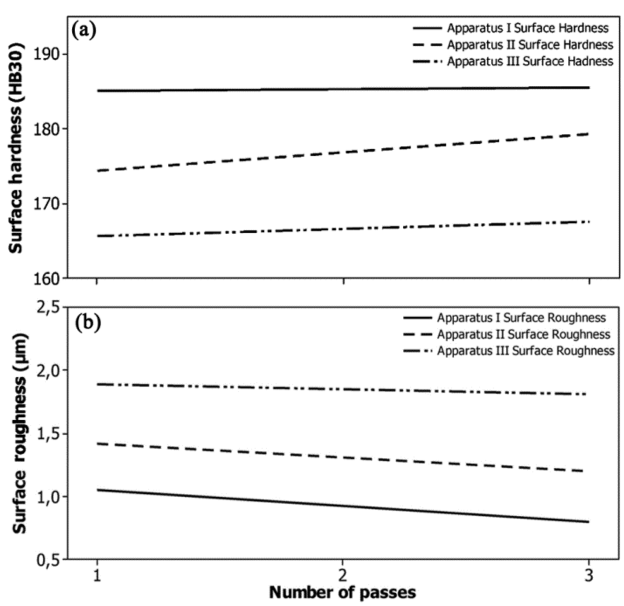

Fig. 7 — General effect of the change of number of passes on (a) surface hardness and (b) surface roughness

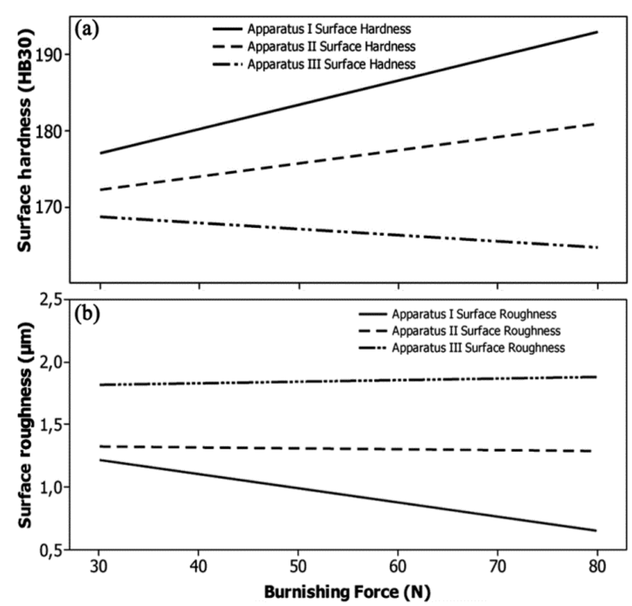

Fig. 8 — Effect of the change of burnishing force (N) on (a) surface hardness and (b) surface roughness

Assessment of experimental results by the artificial neural networks

Artificial neural network is a computer architecture composed by simple and well connected neurons (processors) developed similar to biological nervous system. The processors are like the biological neurons of human brain. In this system, each neuron within the network are connected with different connection weights and rates compared to other neurons. By receiving multiple inlets from more than one neuron, they provide a single output which can reach to other neurons.[19]

In the ANN model, "total function" summing up the weighted inlets provided in Eq. (1) has been used as junction function and Logistic Sigmoid provided in Eq. (2) have been used as transfer function. The specifications are normalized for the range of requirement-limitation inlets and data at outlet layer (0, 1).

$$NETi = \sum w_{ij} \, . x_j + w_{bi} \qquad \ldots (1)$$

$$f(NETi) = \frac{1}{1+e^{-NETi}} \qquad \ldots (2)$$

ANN model has been developed by using the computer program MATLAB.[20] In the first step of training procedure, it is specified which training algorithm will be used. An arrangement is made for the hidden layer number to be one or more, and the number of processor for inlet, hidden and outlet layers are entered. After entering the number of layers, the iteration number is entered by the user and then the training procedure starts. Training continues until the end of iteration or until reaching the required error amount. When the training procedure ends, ANN model's representative results corresponding to mathematical calculation results are obtained.

Test procedure

In order to understand whether ANN is well trained or not, test data other than the training data which it has never encountered are presented to ANN, and it is checked whether it provides correct results or not. In order to compare, statistical values such as statistical data RMSE (Root Mean Squared Error), R^2 (percentage of absolute change), average error % have been used.[21-24] These values are provided by the following equations:

$$RMSE = \sqrt{\left({}^{1}\!/_{p} \sum_J \left| t_j - o_j \right|^2 \right)} \qquad \ldots (3)$$

$$R^2 = 1 - \left(\frac{\sum_j (t_j - o_j)^2}{\sum_j (o_j)^2} \right) \qquad \ldots (4)$$

where t is the target value, o is the outlet value and p is the number of samples.

While designing the algorithm of artificial neural networks, feed rate, pressure force, number of passes and apparatus number being the variables of experiment have been included in the inlet layer on ANN model as shown in Fig. 9. The data on the inlet layer have been assessed by transfer functions on the hidden layer. And in the outlet layer, values of surface roughness and surface hardness are obtained.

Operations with different algorithms are able to be performed by ANN. The algorithms of back dispersion of error generally provide better results in the solution of engineering problems. After composition of artificial neural network, the training algorithm among the back dispersion of error algorithms being the most proper one for this experiment set has been determined. By this purpose, networks consisting of 1 and 2 hidden layers and having different neuron numbers are tested by different training algorithms. This method has different algorithms (i.e. Polak-Ribiere conjugate gradient [CGP], Scaled conjugate gradient [SCG] and Levenberg-Marquardt [LM]). In order to obtain the smallest error, 84 ANN model of different neuron structures has been composed by these three different algorithms. 500 iterations have been preferred in the composed ANN model. It is determined that iterations over this number converts the system to a structure which memorizes rather than learns.

In the ANN structure, the test data and data to be used for training shall be separated. In ANN, the separation of test data had been realized as 70% training and 30% test. These rates are being made by experiment results taken randomly from the experiment set within the program.

In the surface improvement studies by subjecting to burnishing process, the surface roughness and surface hardness values are trained by using

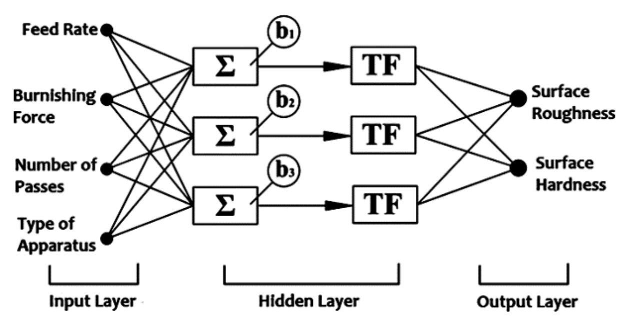

Fig. 9 — Artificial neural network model

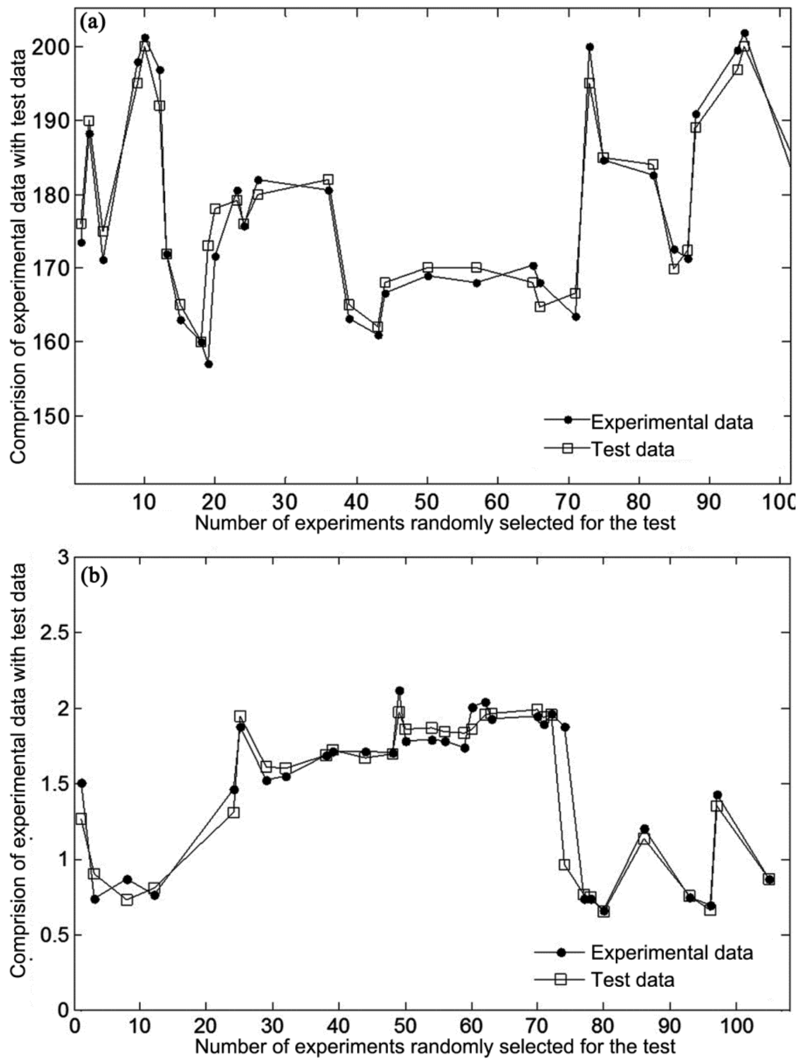

Fig. 10 — Performance values at the layer of CGP algorithm with 3 neurons and 15 hidden layers of randomly selected test group (a) test results of surface hardness and (b) test results of surface roughness

3 different algorithms (LM, SCG and CGP) and 1 and 2 hidden layers and various numbers and forms of neurons within ANN. When a single hidden layer is used, it can be said that training and test sets provide satisfactory results. In this experiment set, the best results are obtained from the CGP algorithm consisting of 15 hidden layers and 3 neurons.

The estimation performances of surface roughness and surface hardness of the test group obtained by using CGP algorithm are provided in Fig. 10 (a,b).

When the ANN results are assessed by statistical error analyses; training set R^2 values are found as 0.948947081, test set R^2 values had been found as 0.897912721, training set RMSE value is found as 3.15534E-02, test set RMSE value is found as 4.78955E-02, training set average error is found as 0.051052919% and it is found as 0.102087279% in the test set for surface hardness of the CGP algorithm 15 hidden layer ANN model. In the same figure, training set R^2 values are found as 0.977947021, test set R^2 values are found as 0.917952611, training set RMSE values are found as 2.11211E-03, test set RMSE values are found as 2.34645E-01, training set average error is found as 0.022052979% and it is found as 0.082047389% in test set for surface roughness.

Conclusions

The effects of burnishing force, feed rate, number of passes and burnishing apparatus being the burnishing parameters used in the burnishing process performed by crushing the surface and without machining are examined under the conditions of current experiment and modeled by ANN. The following conclusions may drawn from this study:

(i) Low feed rate, high pressure force and high number of passes generally provide the best results in decreasing the surface roughness and in increasing the surface hardness.

(ii) All apparatuses used in the experiments have positive effect in decreasing the surface roughness and in increasing the surface hardness. Compared to other apparatus, the experiments performed by ball apparatus may be selected in order to reach the best surface roughness and best surface hardness.

(iii) In the case of best improvement, the surface roughness has been realized at the level of 0.423 μm, and this result is obtained by ball apparatus (Apparatus I). And the lowest surface improvement is obtained by the double roller apparatus (Apparatus III) with a roughness value of 2.643 μm. In the experiments performed, it is observed that the improvement of surface roughness had realized in the range of 21% - 750%.

(iv) The best surface hardness is increased by 45% and has been realized as 200.67 Brinell (HB30) by the ball apparatus (Apparatus I). And the lowest surface hardness value improvement is obtained by the double roller apparatus (Apparatus III) as 153.8 Brinell (HB30). In the experiments performed, it is observed that the improvement of surface hardness is realized in the range of 10% - 45%.

(v) The error rates in ANN model are at acceptable level for the experimental studies. The best ANN model can be obtained by using CGP algorithm fifteen hidden layers and three neurons.

Referances

1 El-Axir M H, *Int J Mach Tools Manuf*, 40 (2000) 1603-1617.
2 Korzynski M, *J Mater Process Technol*, 209 (2009) 625-633.
3 El-Axir M H, Othman O M & Abodiena A M, *J Mater Process Technol*, 196 (2008) 120-128.
4 Korhonen H, Laakkonen J, Hakala J & Lappalainen R, *Mach Sci Technol*, 17 (2013) 593-610.
5 Balland P, Tabourot L, Degre F & Moreau V, *Int J Mach Tools Manuf*, 65 (2013) 29-36.
6 Avilés R, Albizuri J, Rodríguez A & López de Lacalle L N, *Int J Fatigue*, 55 (2013) 230-244.
7 Huuki J, Laakso VA S, *Proc Inst Mech Eng, Part B:J Eng Manuf*, 227 (2012) 45-53.
8 Sarhan A A D & El-Tayeb N S M, *Int J Adv Manuf Technol*, 71 (2014) 1143-1150.
9 Shiou F J & Chuang C H, *Prec Eng*, 34 (2010) 76-84.
10 Taylor P, *Tribol Trans*, 54 (2011) 96-103.
11 Grzesik W & Zak K, *Prec Eng*, 37 (2013) 849-855.
12 Shiou F J & Cheng C H, *J Mater Process Technol*, 201 (2008) 554-559.
13 Pa P S, *Int J Adv Manuf Technol*, 49 (2010) 147-154.
14 Basak H & Goktas H H, *Mater Des*, 30 (2009) 1275-1281.
15 Tang S H, Hakim N, Khaksar W, Sulaiman S, Ariffin M K A & Samin R, *Int J Mach Learn Comput*, 6 (2012) 825-830.
16 Esme U, Sagbas A, Kahraman F, Kulekci M K, *Mater Technol*, 5 (2008) 215-219.
17 Basak H, Sonmez F, *J Polytech*, 18 (2015) 25-132.
18 Minitab Statistical Software (Release 16), Minitab Inc., State College, PA,2010.
19 Sreekanth S, Ramaswamy H S, Sablani S S, Prasher S O, *J Food Process Preserv*, (1999) 329-348.
20 MATLAB (Release 2009b), The Language of Technical Computing, The MathWorks, Inc., Natick, MA, 2009.
21 Arcaklıoğlu E, *Int J Energy Res*, 28 (2004) 1113-1125.
22 Sözen A, Arcaklıoğlu E, Özalp M & Çağlar N, *Renewable Energy*, 30 (2005) 7 1075-1090.
23 Sözen A, Arcaklıoğlu E & Özkaymak M, *Appl Energy*, 81 (2005) 209-221.
24 Toktaş İ & Başak H, *Technology*, 9 (2006) 169-177.