WOOD RESEARCH
54 (3): 2009
89-98

APPLICATION OF NEURON NETWORKS FOR THE PROGNOSTICATION OF THE PROCESSING QUALITY OF LAMINATED PARTICLEBOARDS

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ABSTRACT

The paper presents an application of neuron networks with fuzzy logic algorithms to determine the quality of processing of laminated particleboards on the basis of some selected parameters of the machining process such as: the machining force, edge radius and the work needed to create a new surface. The difficulty of investigations was the determination of the basic effect of the machining process, i.e. the quality for the most heterogeneous and the most difficult for machining wood based material. The authors decided to use artificial neuron networks for the machining analysis because other methods of process assessment and prognostication based on classical methods of statistical and mathematical analysis turned out to be inadequate. The performed investigations showed usefulness of neuron networks for the analyses of the machining process of laminated particleboards and revealed the significance of the relation of the processing quality of these materials with forces occurring during machining.

KEY WORDS: neuron networks, fuzzy logic, machining, particleboard, quality, diagnostics

INTRODUCTION

Laminated particleboards constituting one of the basic raw materials in furniture industry although many problems connected with their processing. These problems are most frequently associated, on the one hand, with the accelerated wear of machining tools and, on the other, with the assurance of the appropriate processing quality. While the improvement of tools, among others, by the introduction of new machine tool materials more durable and resistant to wear (Saljé and

Stühmeier 1988, Labidi et al. 2005) and by launching construction modifications (Boucher et al. 2004, Boucher et al. 2007) has now become an accepted fact, the processing quality of laminated particleboards continues to present considerable difficulties. The heterogeneity of the particleboards structure causes that any attempt at the unification and standardisation of processing parameters is very difficult. This makes it essential to identify those processing factors which are possible to determine directly during the machining and which are associated with the final processing quality. These factors include machining forces (McKenzie et al. 2001). A significant correlation between the normal force and the processing quality was found. Bouzakis et al. (2003) proposed an optimisation algorithm of milling processing focused on the quality of the processing surface measured by its roughness. The input values for the algorithm include, among others: number of blades, feed per blade and depth of machining. On the basis of these data, supported by mathematical models connecting them with forces occurring during processing, it is possible to prognosticate surface roughness.

Although the above literature reports are very promising, it may very well turn out that the application of the results of these investigations in industrial conditions will be difficult or even impossible. The raw material used to manufacture particleboards (small-size timber, industrial wastes, and recycling materials) as well as various impurities (mainly bark and sand) and production defects of boards by lamination all contribute to the fact that each batch of manufactured laminated particleboards is unique. For this reason, the production realities do not allow carrying out detailed property investigations of particleboards with regard to a particular production batch and, on this basis, assessing or prognosticating the most important production criterion, namely the product quality. Therefore, in this situation, it is necessary to apply special mathematical models dedicated to particleboards which, on the basis of set factors and the actual machining force could: 1- effectively, accurately and, even more important, in real "*on-line*" time determine the processing quality and possibly introduce appropriate corrections of processing parameters and 2- on the basis of test sample machining, define and characterise the cutting properties of particleboards. Artificial neuron network models are characterised by the above-mentioned properties. Such unique characteristics of neuron networks as the capability to learn and predict trends on the basis of the analysed historic data allow employing these networks either as supplementary tools or complete replacement of classical methods of mathematical and statistical analysis in processing of extremely heterogeneous laminated particleboards.

Teshima et al. (1993) obtained results of the application of neuron networks for the estimation of cutting tool life. Zbiec (2004) obtained results of the application of neuron networks for the prognostication of the condition of the machining blade on the basis of machining forces, temperature, vibrations and power consumption. In his study, he demonstrated the failure of statistical methods and mathematical models in the situation of a considerable scatter of investigation results. In these conditions, the neuron network applied by him and based on the algorithm of the three-layer, non-linear perceptron with a reverse error propagations (REP) turned out to be an effective system of diagnosing the degree of blunting of the tool.

Taking into consideration particular properties of laminated particleboards selected data of process parameters supported with artificial intelligence gives possibility to control products quality. To verify this hypotesis the fallowing objective of work was constituted. The objective of this research project was an attempt to apply selected algorithms of artificial intelligence, in particular artificial neuron networks, for the prognostication of the processing quality of laminated particleboards on the basis of selected parameters of the machining process.

MATERIAL AND METHODS

The authors, following preliminary tests, decided to carry out the analysis of the dependence of the processing quality on selected machining parameters with the assistance of neuron networks on the basis of the following input data:

- edge radius (r),
- area of the laminate damage (A_u),
- work of new surface creation (L_A),
- extreme value of the of the second degree multinomial ($_{pik}F_{z\,max}$) describing the dependence of the $F_{z\,max}$ force on the height of the machining layer h described on Fig. 1.

The input data for this study were collected in the process of milling of 16 types of commercial three-layer laminated particleboards. The processing was performed on an equiped industrial spindle moulder for wood using a kit of replaceable blades of a set edge radius ranging from r 5-70 micrometers at regulated height of the machining surface and machining speed and constant travelling speed. The following forces were registered during processing: F_x – force parallel to the direction of the travel of the material and the normal force F_z - perpendicular to the travel of the material. The experimental station employed in the tests is presented on Fig. 2. Two piezoelectric sensors measuring forces in the three directions of the Cartesian co-ordinate system were placed in the sample chuck. The force signals obtained in this way were then amplified by an amplifier, transformed by an analogue-digital converter and next registered individually and then added up in a computer.

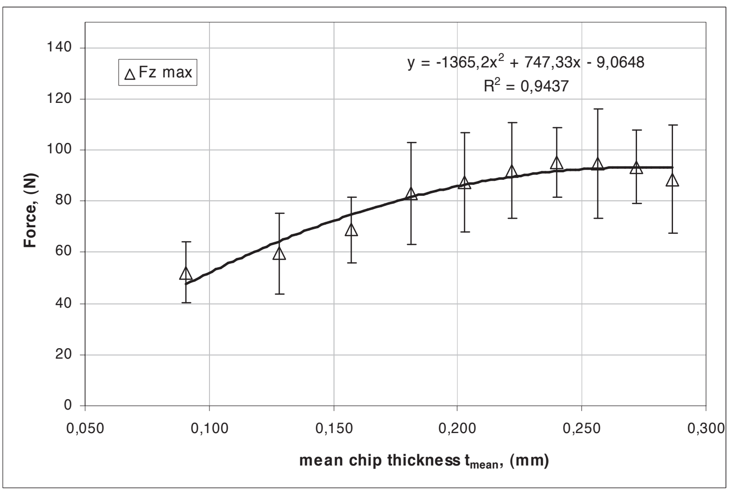

Fig. 1: Maximum value of the F_z force ($_{pik}F_{z\,max}$) in the function of mean thickness of the chip for the Ml board

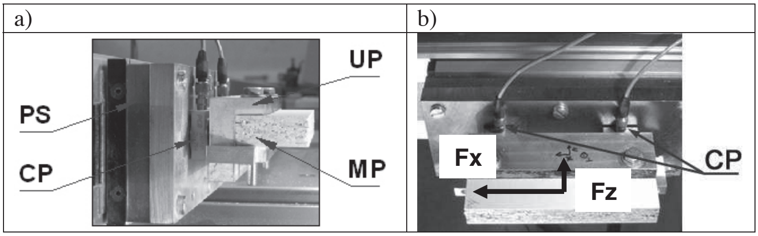

Fig. 2: View of the support of the feeding device: a) from the side, b) from the top; PS – mobile carriage, CP - piezoelectric sensor, UP – sample chuck, MP – particleboard's sample, Fx – feeding force, Fz – normal force

The following three values were determined from the course of the F_x force (Fig. 3):

- the value of the force initiating the failure $F_{x\,0}$,
- value of the F_x force at the mean thickness of chip, $F_{x\,mean}$,
- maximum value of the $F_{x\,max}$.

The following values were determined from the course of the F_z force (Fig. 4):

- value of the F_z force at the mean chip thickness $F_{z\,mean}$,
- maximum value of the $F_{z\,max}$ force.

On the basis of the measured forces, the authors determined values of the specific machining work L_S, work of developing a new surface L_A and the work of chip deformation L_W (Beer et al., 2005; Kowaluk et al., 2004). Especially, the value of the specific work of developing a new surface was calculated on the basis of the F_{x0} value, i.e. the force which initiated breaking at zero thickness of the chip. The value of this force was determined on the basis of the analysis of the curve course of the F_x force in time (Sinn et al., 2005).

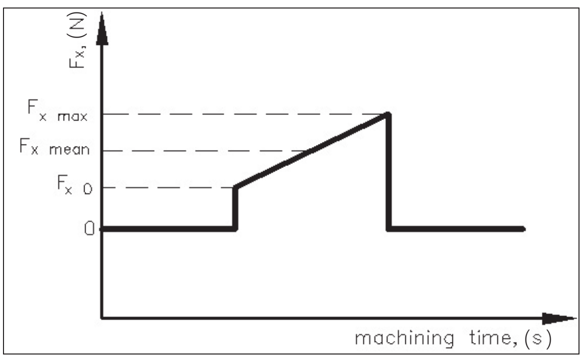

Fig. 3: Course of the F_x force for a single chip and its determined values

The processing quality was determined by measuring the surface of the laminate damages on the wide surface of the board A_u. The collected data were subjected to analysis with the assistance of the Neuro Solutions 5.0 program of the NeuroDimension, Inc.

The performed analyses of the possibilities of utilising different models of neuron networks showed that the most suitable model for the diagnosis of the quality of particleboards processing would be the network model employing the algorithms of fuzzy logic.

The following variable parameters of the processing were distinguished: the edge radius, the height of the machining layer and the speed of machining.

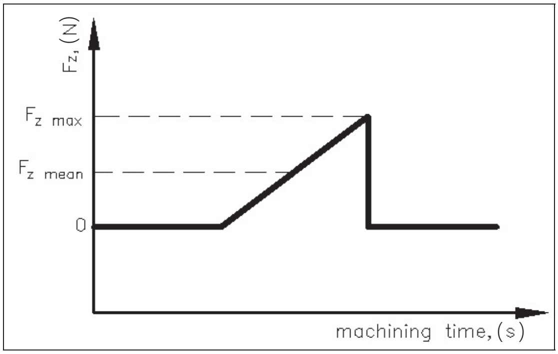

Fig. 4: Course of the F_z force for a single chip and its determined values

RESULTS AND DISCUSSION

The first step in the analysis of the interrelationships of test data for the edge radius was to determine correlations between the surface of laminate damage A_u and the remaining input parameters. In this way, a tabular list of values of the wanted correlation was obtained:

$$A_u = f\left(r, L_A, {}_{peak}F_{z\max}\right) \quad (1)$$

where: r – edge radius, L_A – specific work of developing a new surface, ${}_{pik}F_{z\,max}$ – multinomial extreme of the second degree describing the dependence of the $F_{z\,max}$ force on the height of the machining layer.

In the consecutive step, assuming the continuity of the above function (for similar input values, the result of the function should be similar), the authors looked for such groups of input data (r, LA, ${}_{peak}F_{z\,max}$) which differed from one another by less than 20%. This came down to searching for those points from the space with dimensions (r, LA, ${}_{peak}F_{z\,max}$) which are close to one another. In this way, data were divided into 16 groups. Because of considerable inconsistencies preventing the allocation of 4 results to any specific group, they were treated as severe error and removed from further analyses.

However, since values of damages A_u in each of the groups determined in this way differed from one another (although, theoretically, they should be similar), the mean value A_u was calculated for each group and next, depending on this mean, the data were allocated into classes from 1 to 4. The size of individual classes was as follows: Kl1 – 2 results, Kl2 – 8 results, Kl3 – 49 results and Kl4 – 31 results. The expediency of the above simplification procedure was confirmed by considerable streamlining of calculations.

The classes included the following intervals of mean values of laminate surface damages A_u:

0	<	**Kl1**	<	111,6
111,6	<	**Kl2**	<	136,6
136,6	<	**Kl3**	<	161,6
161,6	<	**Kl4**		

Prior to the initiation of the learning process of the network, a random sample of 10 measurements was excluded from input data with the aim to apply them later to control the correctness of the operation of the network.

On the basis of data prepared as described above, the process of learning of the network was carried out. Its objective was to develop in the fuzzy logic algorithm the capability to ascribe the implied data: r, L_A and ${}_{pik}F_{z\ max}$ to one of the above classes. The results of the process are presented in Tab. 1.

In the Tab. 1, column "Kl" contains the name of the class to which a given result was ascribed in accordance with the above procedure. Columns "Out K11" to "Out K14" contain information (network proposals) in absolute values about to what extent a given result introduced into the network algorithm in the course of testing corresponds to a given class. The next column designated "MAX" indicates the highest percentage value of the degree of the match of a given testing result to the selected class. The last of the table columns of the logic type "TRUE/FALSE" compares the proposal of ascribing of a given result to a specific class with the true membership of the result to the specific class. The application of the fuzzy logic allows, additionally, the identification of a case in which the network "hesitates" when allocating a result to a specific class. A good example of this situation is the first row in the data table where the network in 64% recommends the allocation of the result to class 3 but, at the same time, in 43% - to class 1 and, in fact, it is the latter allocation that should be selected in this particular case (and not the maximum value, i.e. class 1).

Tab. 1: Testing results of the neuron network

Kl	Out Kl1	Out Kl2	Out Kl3	Out Kl4	MAX		TRUE/FALSE
Kl1	0,43	0,12	0,64	-0,28	64%	**Kl3**	FALSE
Kl2	0,01	-0,02	0,19	0,82	82%	**Kl4**	FALSE
Kl3	0,00	0,06	1,04	-0,11	104%	**Kl3**	TRUE
Kl3	-0,02	-0,02	0,61	0,42	61%	**Kl3**	TRUE
Kl3	0,04	-0,09	0,99	0,07	99%	**Kl3**	TRUE
Kl3	0,04	0,09	0,98	-0,11	98%	**Kl3**	TRUE
Kl4	-0,04	0,09	0,06	0,87	87%	**Kl4**	TRUE
Kl4	0,14	0,19	0,04	0,62	62%	**Kl4**	TRUE
Kl4	-0,05	0,11	-0,11	1,03	103%	**Kl4**	TRUE
Kl4	0,01	0,12	0,00	0,90	90%	**Kl4**	TRUE

It is evident from the data in this table that, in general, for large-size classes, such as K13 (49 results) and K14 (31 results) the network allocates them properly on the basis of the learnt input results. It is only in the case of small-size classes, such as K11 (2 results) or K12 (8 results), that the networks gives erroneous proposals of classification when assessing the results. Therefore, out of 10 measurements which were not used during network testing but were implied as test data, 8 measurements were classified correctly.

Additionally, in order to assess the so called 'network sensitivity', the authors carried out the analysis of significance of individual input parameters on the result of network operation. It was possible to conduct this analysis thanks to the above-mentioned Neuro Solutions 5.0 program. The obtained results were as follows:

- the effect of r : 25%,
- the effect of L_A : 39%,
- the effect of ${}_{pik}F_{z\,max}$: 36%.

The above-described analysis was further supplemented by descriptive statistics of the data for classes 3 and 4 as well as all four classes (Tab. 2).

Tab. 2: Descriptive statistics for values of damaged areas of the laminate taking into account individual classes

	Kl3	Kl4	Total (Kl1-Kl4)
Mean	152	187	160
Standard error	7	14	7
Standard deviation	54	80	68
Sample variance	2918	6453	4568
Minimum	60	72	60
Maximum	316	374	374
Confidence interval (90%)	12	23	11

An attempt to perform a similar analysis for the board thickness after processing showed that, because of the range of variability of this parameter which is smaller than the variability range of laminate damage area, the mean value of all samples may turn out to be a more advantageous solution as the best approximation of the predetermined function.

In the result of analysis of test data for the variable value of the height of the machined layer, 6 main groups were obtained containing from 1 to 6 particleboards. The grouping criterion did not take into account the value of the area of damages of the laminate. In each group, the parameters of individual boards differed from the mean value of the given parameter by not more than 20%. The next board classification into categories of similar sizes of damaged areas distinguished 4 classes of 1 to 9 boards in each. For each board class, basic statistical values of damages, i.e. mean, standard deviation and minimum and maximum values were determined for two levels of confidence: 90% and 80%. In addition, the impact of the significance of the examined parameters on the qualification results was also determined which was performed using the so called analysis of network sensitivity (mean percentage effect of a given parameter on the final result):

- effect of L_A : 24%,
- effect of ${}_{pik}F_{z\,max}$: 53%.

More significant results were obtained in the case of the application of the selected tools of artificial intelligence for the assessment of interrelationships of processing parameters for the variable height value of the machined surface than in the case of tools characterised by gradual blunting. This is associated with the structure of the particleboards and defects resulting from covering it with laminate.

In the course of the test data for the variable value of the machining speed, 7 main groups were obtained containing from 1 to 4 boards. Also in this case, the grouping criterion did not take into account the value of the area of damages of the laminate. In each group, the parameters of individual boards did not differ from the mean value of the given parameter by the total of more than 20%. The next board classification into categories distinguished 3 basic classes of 3 to 6 boards in each class. The analysis of these results failed to distinguish characteristic classes and parameters because in several cases boards were allocated to different classes. The obtained results indicate that, in this case, the machining speed was a dominating factor which "suppressed" the material characteristics of boards.

CONCLUSIONS

Summing up the above-described analysis of results with the assistance of neuron networks using fuzzy logic obtained for 16 commercial particleboards, the following conclusions can be drawn:

- the hypotesis was positively verified; neuron networks with fuzzy logic algorithms provide a valuable tool for the analysis of processing, in particular, in the case of very heterogeneous materials, such as laminated particleboards; it is especially helpful when properties, such structure, are changed and the products quality are difficult to be predicted,
- the work of developing a new surface and the extreme value of the multinomial of the second degree describing the dependence of the normal force on the height of the machined surface constitute the most important parameters for the process of diagnostics and the quality assessment of laminated particleboards,
- bearing in mind the heterogeneous structure of particleboards and defects in the lamination process, data for network learning can be obtained by repeating tests for a given boards several times,
- it is advisable to carry out measurements for boards of different properties in order to prevent domination of one class of boards. However, if there is such a dominating class, it is recommended that the analysis for this class should be carried out separately.
- in the case of insufficient number of board measurements and additionally with a dominating group of boards ascribed to one class, the obtained results are characterised by the following traits: 1 – after the introduction of data into the network training, a function develops which in fact is a function similar to a linear one with the value equal to the mean from measurements; 2 – for similar values of the input vector, the sought function ascribes considerably varied results which indicates randomisation of the sought function; 3 – there is no basis which would allow the utilisation of the neuron network for the prognostication of the value of laminate damages employing the above-mentioned parameters because comparable results can be obtained using the statistical analysis of the damage mean and its distribution,
- forces occurring during processing and the distribution of work necessary to perform the machining process provide a useful indicator of the processing diagnostics and prognostication of quality classes resulting from material traits of laminated particleboards.

ACKNOWLEDGEMENT

The authors wish to thank Dr Milojka Gindl and Dr. Gerhard Sinn for their kind cooperation in preparing the initial data. This study has been carried out with the financial support of the OeAD, MNiSW and project N30902532/2780.

REFERENCES

1. Beer, P., Sinn, G., Gindl, M., Tschegg, S., 2005: Work of fracture and of chips formation during linear cutting of particle-board. Journal of Materials Processing Technology 159: 224-228
2. Boucher, J., Meausoone, P.J., Perrin, L., 2004: Effects of diamond tool edge direction angle on cutting forces and tool wear during milling of medium density fiberboard, and particleboard. Proceeding of the 2nd International Symposium on Wood Machining, Vienna, Austria, Pp. 241-248
3. Boucher, J., Meausoone, P.J., Martin, P., Auchet, S., Perrin, L., 2007: Influence of helix angle and density variation on the cutting force in wood-based products machining. Journal of Materials Processing Technology 189: 211-218
4. Bouzakis, K.D., Aichouh, P., Efstathiou, K., 2003: Determination of the chip geometry, cutting force and roughness in free form surfaces finishing milling, with ball end tools. International Journal of Machine Tools & Manufacture 43: 499-514
5. Kowaluk, G., Dziurka, D., Sinn, G., Beer, P., Tschegg, S., 2004: Influence of particleboards production parameters on work of fracture and work of chips formation during cutting. Electronic Journal of Polish Agricultural Universities, Wood Technology, vol. 7(1): 1-8
6. Lacki, W., 2003: Application of intelligent techniques in project management. Materials of Project Management, published in internet
7. Labidi, Ch., Collet, R., Nouveau, C., Beer, P., Nicosia, S., Djouadi, M.A., 2005: Surface treatments of tools used in industrial wood machining. Surface and Coatings Technology 200: 118-122
8. McKenzie, W., Ko, P., Cvitkovic, R., Ringler, M., 2001: Towards a model to predict cutting forces and surface quality in routing layered boards. Wood Science and Technology 35: 563-569
9. Saljé, E., Stühmeier, W., 1988: Milling laminated chipboard with tungsten carbide and PCD. Industrial Diamond Review 4: 319-326
10. Sinn, G., Beer, P., Gindl, M., Patsch, R., Kisselbach, A., Standler, F., Stanzl-Tschegg, S., 2005: Analysis of cutting forces in circumferential flat milling of MDF and particleboard. Proceedings of the Int. Wood Machining Semin. 17, Rosenheim, Germany, Pp. 80-87
11. Teshima, T., Shibasaka, T., Takuma, M., 1993: Estimation of cutting tool life by processing tool image data with neural network. Annals of CIRP no 42/1
12. Zbiec, M., 2004: Diagnostics of tools blunting in wood based materials milling. dissertation, Warsaw University of Life Sciences, 151 pp.

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