TRIESKOVÉ A BEZTRIESKOVÉ OBRÁBANIE DREVA, 9(1): 37–42, 2014
Zvolen, Technická univerzita vo Zvolene, ISSN 1339-8350

INCREASE IN SOME QUALITY INDICATORS OF PARTICLEBOARDS BY OPTIMIZING SURFACE LAYERS – PART II

Tsvetelin Evstatiev

Abstract

Optimization of quality of products and manufacturing processes is one of the main tasks of managers in particleboard factories.

Optimization of particle size, binder content in surface layers and surface/core layer ratio at set limitations for standardized requirements of bending strength (MOR), modulus of elasticity (MOE) and internal bond (IB) strength perpendicular to the plane of the board of PBs is presented in the paper.

The results show that, in the investigated ranges of variation of input parameters, the output indices cover the minimum requirements for boards for load-bearing structures for use in dry environment.

Key words: *PBs, planned experiment, quality, optimization.*

INTRODUCTION

For manufacture of products of optimum quality, knowledge of the effect of input factors on output quantities is not enough. For this, it is necessary to establish and mathematically express the relationship between the input and output quantities and through it to look for their optimum values at given requirements.

The increase in quality of products is often related to increase in costs. The use of a planned experiment and optimization of results obtained allow revealing possibilities for increasing the quality indicators without this being at the expense of costs.

The aim of this paper is to optimize the results obtained from a planned experiment investigating the effect of size of sieve through which the particles for surface layer have passed, binder quantity in surface layer (SL) and surface/core layer (SL/CL) ratio on mechanical indices of particleboards (PBs).

MATERIALS AND METHODS

To optimize the mechanical indices of PBs, results of a planned experiment conducted according to combined D-optimum plan have been used. The plan of the experiment (Table 1) has been generated by means of the QStatLab software programme.

University of Forestry, 10 “Kliment Ohridski” Blvd., 1756 Sofia, Bulgaria
e-mail: ceevstatiev@abv.bg

Industrially obtained particles for core layer to the softwood/hard hardwood ratio of 70/30% have been used. The particles used for surface layer have a size corresponding to fractions 3/2; 2/1; 1/0, and for the core layer – to fraction 4/0.5 mm. The particles for FL and CL have been dried to 3.5% moisture content. The binder is urea-formaldehyde (UF) resin with jellying time of 45-50 s and 8% participation in the core layer. 2.2% and 0.7% ammonium sulphate has been added to the resin in the role of hardener, respectively for core and surface layer. The manually formed mat has been subjected after cold pressing to hot pressing at panel temperature of 195 °C, maximum pressure of 2.8 MPa for 240 s. The set density is 680 kg/m^3.

To establish the effect of factors used and optimization of mechanical indices of PBs, a reduced model of second power (Vuchkov, I.N., S.K. Stoyanov, 1980) has been used. At number q of interdependent factors (surface/core layer) and number $r = m - q$ of mutually independent factors (resin quantity in SL and particle size), the reduced polynomial model $\hat{y}$ of second power has the following form:

Table 1. Generated D-optimum plan of the experiment

	Resin in SL, %	Size of sieve, mm	CL, %	SL, %
	X1	X2	X3	X4
1	8	1	80	20
2	14	1	80	20
3	8	3	80	20
4	14	3	80	20
5	11	1	60	40
6	8	2	60	40
7	11	2	80	20
8	11	3	60	40
9	14	2	60	40
10	14	3	70	30
11	11	2	70	30
12	8	3	70	30
13	14	1	60	40
14	8	1	60	40
15	8	3	60	40

$$\hat{y} = \sum_{i=1}^{q} b_i x_j + \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} b_{ij} x_i x_j + \sum_{i=q+1}^{m} b_{ii} x_i^2 \tag{1.1}$$

where: m is the total number of factors, b – regression coefficients, x_j – interdependent factors, x_i mutually independent factors.

The adequacy of the models is checked by means of comparison of the calculated F_0 and theoretical values F of Fisher's F-test. When $F_0 > F$, then the model is adequate. The accuracy of prediction of the index according to the given model is expressed by means of the coefficient of determination of the prediction $R^2(pred)$.

The optimization has been realized at imposed standard limitations after the method of random search (Vuchkov, I.N., S.K. Stoyanov, 1980).

Pursuant to the standard EN 312:2010, the minimum requirements to boards of type P4 (boards for load-bearing structures for use in dry environment) are: MOR > 15 N/mm^2; MOE > 2300 N/mm^2; IB > 0,35 N/mm^2.

According to the standard EN 326-2:2010, the mean values of the manufactured boards must be above the minimum requirements with a probability of 95%, i.e.

$$\min \mathrm{MOR} > \bar{\bar{X}}_{MOR} - t_{n-1;0.05} \bar{S}_{MOR,n} \tag{1.2}$$

$$\min \mathrm{MOE} > \bar{\bar{X}}_{MOE} - t_{n-1;0.05} \bar{S}_{MOE,n}$$

$$\min \text{IB} > \overline{\overline{X}}_{IB} - t_{n-1;0.05}\overline{S}_{IB,n}$$

where min MOR, min MOE, min IB are the minimum requirements according to the standard, $\overline{\overline{X}}$ is the mean value of the mean values of *n* boards, $t_{n-1;\,0.05}$ – theoretical value of the Student's *t*-criterion, at degrees of freedom *n-1* and confidence level of 0.05, $\overline{S}_n$ – mean variance of *n* boards.

It is shown in the standard EN 326-2:2010 that $n = 30$, at which $t_{n-1;\,0.05}$=1.7.

It has been established in previous investigations that the mean variances for the individual indices are respectively: $\overline{S}_{MOR,n}$ =1.2 N/mm^2; $\overline{S}_{MOE,n}$ = 230 N/mm^2; $\overline{S}_{IB,n}$ = 0.04 N/mm^2.

This means that the minimum mean values calculated after transformation of formulae (1.2) for mechanical indices must be: $\overline{\overline{X}}_{MOR}$ > 17 N/mm^2; $\overline{\overline{X}}_{MOE}$ >2700 N/mm^2; $\overline{\overline{X}}_{IB}$ >0.42 N/mm^2. These are the limitations with which the optimization should be performed. An additional limitation is the use of a minimum binder quantity in the board.

RESULTS AND DISCUSSION

The processing of the results and the optimization have been performed by means of the QStatLab software programme. The worked out equations for the mechanical indices of PBs are:

- for MOR (bending strength)

y_{MOR} = -2.6993017x3-43.043605x4+0.02033257x1x1-2.6610398x2x2+1.3926156x1x4+ +14.483634x2x3+47.831625x3x4+17.684023x2x4-0.16644177x1x2 (1.3)

- for MOE (modulus of elasticity)

y_{MOE} = -80.203048x3-5809.3197x4+3.4243117x1x1-250.52386x2x2-21.4557x1x2+ +1431.6229x2x3+6828.1306x3x4+252.86809x1x4+1839.4055x2x4 (1.4)

- for IB (coming unglued strength or internal bond strength perpendicular to the plane of the board)

y_{IB} = 0.1620357x3+0.52858321x4+0.13428463x2x3 (1.5)

Table 2. Values of the calculated F_0, theoretical Fisher's F-test F and coefficient of determination for prediction

	F_0	F	R^2(pred)
MOR	114.88	F(0,05,8,6) = 4.146	0.949
MOE	108.73	F(0,05,8,6) = 4.147	0.952
IB	11.18	F(0.05,2,12) = 3.885	0.467

The calculated values F_0 are greater than the theoretical values F of Fisher's *F*-test (Table 2), from which follows that the equations worked out are adequate and may be used to predict the values of the mechanical indices. The accuracy of the predicted values

R^2(pred) for MOR is 94.9%, MOE is 95.2%. In spite of the adequacy of the model for IB, the accuracy of prediction is relatively low – 46.7%. The input variables of the planned experiment do not affect directly the central zone of the core layer, on the properties of which IB depends. This and the impact of uncontrolled factors during the experiment determine the lower degree of prediction of this index.

The limited areas of solutions and optimum solutions are presented graphically on Fig. 1, Fig. 2 and Fig. 3. It turns out that main limitation is the value of the modulus of elasticity, i.e. this index is most difficult to achieve.

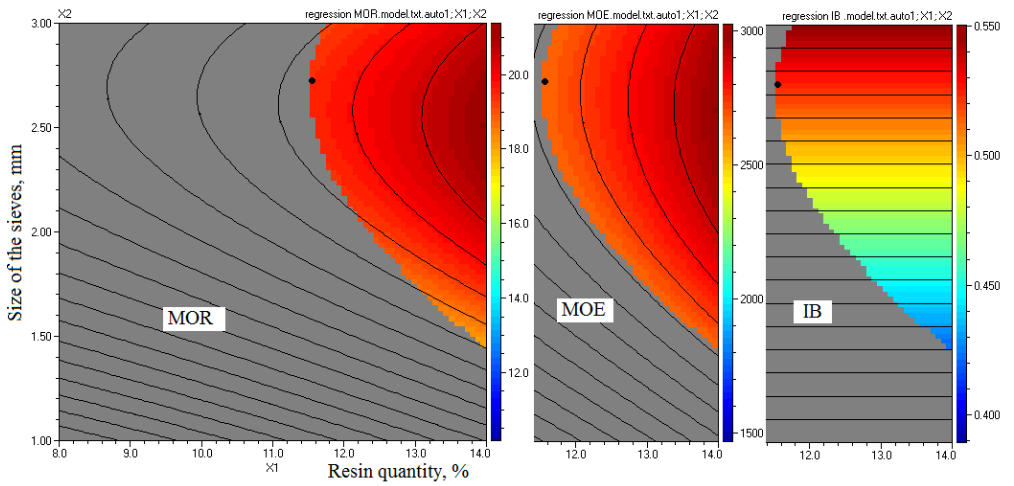

Fig. 1. Lines of constant values at limitations and SL/CL ratio of 40/60% of MOR, MOE and IB and optimum solution at minimum binder quantity

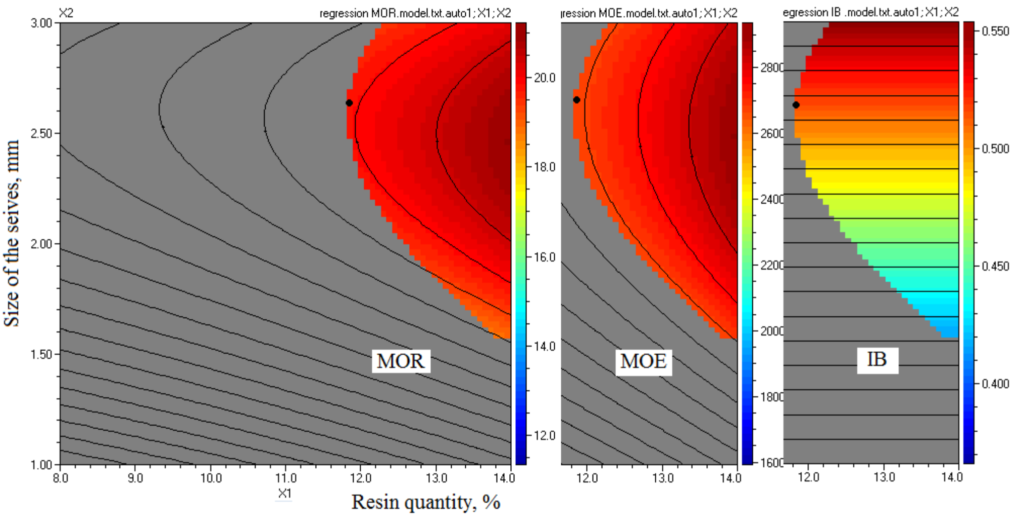

Fig. 2. Lines of constant values at limitations and SL/CL ratio of 30/70% of MOR, MOE and IB and optimum solution at minimum binder quantity

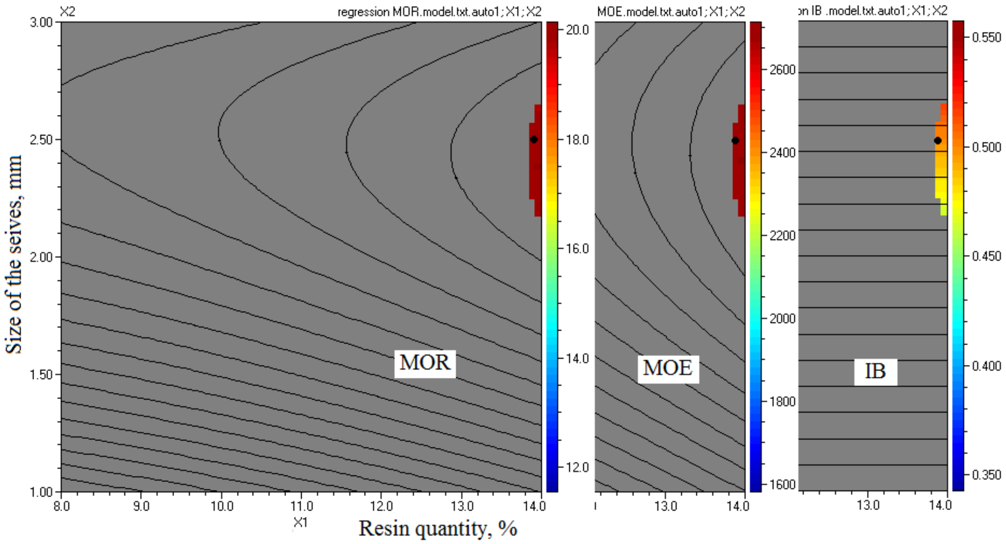

Fig. 3. Lines of constant values at limitations and SL/CL ratio of 20/80% of MOR, MOE and IB and optimum solution at minimum binder quantity

Several solutions are possible at different levels of the input variables (Table 3). This is determined by the imposed additional requirement for minimum total binder quantity. The optimum solution is at values of input variables in variant two. The values are close in variant one.

Table 3. Variants of solutions

	Resin in SL, %	Size of sieve, mm	CL, %	SL, %	MOR, N/mm2	MOE, N/mm2	IB, N/mm2	Total resin in board, %
	X1	X2	X3	X4				
Var. 1	13.9	2.51	80	20	20.03	2702.17	0.54	9.18
Var. 2	11.9	2.6	70	30	20.08	2705.48	0.515	9.17
Var. 3	11.55	2.69	60	40	19.74	2702.32	0.525	9.42
Var. 4	11.53	2.67	65	35	19.92	2700.66	0.523	9.24

Of interest is the fact that, at identical densities and binder quantity, it is possible to obtain boards with higher mechanical indices by means of increasing the particle size in the surface layers and optimization of the surface/core layer ratio.

CONCLUSION

The possible solutions depend on both the limitations (requirements) to the output indices and the limitations imposed on the input variables.

The imposed limitations on the mechanical indices for boards of type P4 (EN 312:2010) are in conformity with the variances attained in the manufacture of PBs.

After the optimization performed, two optimum variants have been proposed (Table 3), in which the total binder quantity in the board is minimum – respectively 9.17% and 9.18%. The particle sizes in this variants are respectively 2.6 mm and 2.51 mm, and the surface/core layer ratio – 30/70% and 20/80%.

ACKNOWLEDGEMENTS
This document was supported by the grant No BG051PO001-3.3.06-0056, financed by the Human Resources Development Operational Programme (2007 – 2013) and co-financed jointly by the European Social Fund of the European Union and the Bulgarian Ministry of Education and Science.

REFERENCES

Vuchkov, I.N., S.K. Stoyanov. 1980. Mathematical modelling and optimisation of process sites. S.

EN 312:2010. Particleboards – Specifications.

EN 326-2:2010. Wood-based panels – Sampling, cutting and inspection – Part 2: Initial type testing and factory production control.