Modeling of Properties of the Oriented Strand Board in STATGRAPHICS

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Abstract

This study is done to obtain experiment-statistical mathematical model of OSB properties depending from two factors: hot pressing stage overall time and hardener content in a binder based on phenol-cardanol-formaldehyde resin. A laboratory scale sample of phenol-cardanol-formaldehyde resin with substitution of 5 % by weight of phenol to cardanol with a molar ratio phenols (phenol + cardanol) to formaldehyde equal 1 to 2.33 (resin grade SFJ-OSB 5K) was prepared in R&D Center of PJSC "Uralchimplast". As the hardener of the resin SFZH-OSB 5K, technical propylene carbonate was used. Average strands dimensions were: 40 - 80 mm length, 20 - 30 mm width and 0,5-0,8 mm thickness. Hot pressing of the wood chips briquette was performed in 11 minutes with heated press plates temperature of 180-190 ° by a three stage regime with maximum pressure of 2MPa. To study the influence of technological factors on the properties of OSB, a three-level full two-factor experiment on the Kono plan was performed, obtaining regression-based experimental statistical models of the properties of the object under study in the Statgraphics Centurion XV program. The received results of researches have shown the good opportunities of program Statgraphics Centurion XV for reception of regression mathematical models of properties of laboratory samples of plates OSB, describing laws of influence of technological factors on them. The resulting regression models, after checking their adequacy under industrial conditions, can be used to predict the properties of OSB and to control their quality.

Introduction

Reduction of employee number with automation and complex operation systems is one of the modern tendencies in production of wood panels [1]. It is expected that a kind of artificial intelligence for operating of this technological processes can appear in the future. Programs for optimizing of production process and quality management of wood panels are key elements for such systems. The knowledge of quantitative dependencies of technology factors influence on properties of wood panels produced in a form of mathematical models is needed for development of programs for optimization of production processes and quality management of wood panels. Regression analysis is one of the effective quantitative methods allowing obtaining of mathematical statistical model of object properties in a form of regression equation with technological parameters taken as arguments. It is recommended to use mathematical plans of laboratory [2,3] and industrial experiments [2,4] for obtaining of mathematical regression models with the most precise considera-

tion of technological factors. In laboratory investigations mostly with one factor experiments the influence of such technological parameters as phenol-formaldehyde resin consumption, pressure and time during hot pressing of boards [5,6,7], urea content in phenol-urea-formaldehyde resins [8] obtained in a form of qualitative dependencies.

In connection with the depletion of oil and natural gas resources in the world, scientific research is under way to replace synthetic chemical compounds with substances derived from renewable plant resources. For the production of wood –based panels phenol-formaldehyde resins (PFR) make up a significant proportion of the polymer binders used. The constant rise in prices for synthetic phenol, proportional to oil prices, leads to the need to address the urgent task of today - reducing the cost of production of the PFR.

The constant rise in prices for synthetic phenol, proportional to oil prices, leads to the need to replace synthetic phenol in the production of PFS with phenols from renewable plant resources (lignins [9-14], tannin [9,10], pyrolysis oils [9, 15 -18], etc. Badamkhand Suklibaatar, Philip H. Steele and Moon G. Kim [12] included pyrolytic lignin in phenol-formaldehyde resins at 30%, 40% and 50% degree of phenol replacement, and the resulting resins were evaluated as binders for layer OSB. Estimates showed that pyrolitic lignin is effective for the binding type of PBS when substituted by 40% for the synthesis of phenol.

Experimental part

A laboratory scale sample of phenol-cardanol-formaldehyde resin with substitution of 5% by weight of phenol to cardanol with a molar ratio phenols (phenol + cardanol) to formaldehyde equal 1 to 2.33 (resin grade SFJ-OSB 5K) was prepared in R&D Center of PJSC “Uralchimplast”. The synthesis was performed in accordance with an actual technical regulation № 071294 to obtain the resin with a viscosity of 30-35 seconds at 20°C by VZ-246 viscometer (Ford Cup with a 4mm outlet diameter). The properties of resin obtained are shown in the Table 1.

Table 1: Properties of SFJ-OSB 5K resin

Parameter name	Parameter value
Apparent viscosity with a VZ-246 viscometer (outlet diameter 4mm), sec.	34
Nonvolatile matter content (solid basis), %	41,8
Alkali content, %	5,50
Residual phenol, %	0,01
Residual cardanol, %	0
Residual formaldehyde, %	0

Propylene carbonate, technical grade, known to speed up phenol-formaldehyde resin curing [19] was taken as a hardener for SFJ-OSB 5K. Dry wood chips (strands) received from OSB manufacturing plant (PE head of PFE Nevzorov A.F., s. Sychevo, Kurgan region) had absolute humidity 4-5%, weight share of absolutely dry softwoods 40% and hardwoods 60%.

Average strands dimensions were: 40 - 80 mm length, 20 - 30 mm width and 0,5-0,8 mm thickness.

Every layer of strands was covered with a precalculated amount of pulverized resin during manual formation of wood carpet with 50:50 ratio between external : internal layers. Big starnds were oriented in one direction in outer layer while smaller strands were oriented perpendicular in internal layer.

After 1 minute of cold prepressing at 1MPa pressure, hot pressing of obtained wood chips briquette was performed in 11 minutes with heated press plates temperature of 180-190°C by a three stage regime with maximum pressure of 2MPa. Thus obtained OSB board was further conditioned before testing for 3 days at room temperature.

Results of experiments and analyses

In order to study the influence of technological parameters on properties of OSB boards a full three level complete two-factor experiment by design related to D-optimum Kono designs (design Ko-2) was performed. Kono designs for normalized incoming values have good statistical characteristics and thrifty for number of experiments [3].

Intervals of input parameters in experiment held are shown in Table 2, its design and results are in Table 3.

Table 2: Intervals of input parameters

Input parameters	Natural values of input parameters (Z_i) at their normalized values (x_i)		
	$x_i = -1$	$x_i = 0$	$x_i = +1$
Propylene carbonate content in a binder, % by weight counted on absolutely dry resin (Z_1)	0	0,5	1
Overall time of hot pressing, min. (Z_2)	9	11	13

The following properties of OSB boards were taken as output parameters (y_i):
σ – bending strength over the board main axis, MPa (y_1);
Δh_2 – swelling by thickness after 2 hours in water, rel. % (y_2);
Δh_{24} – swelling by thickness after 24 hours in water, rel. % (y_3);
W_2 – water absorption in 2 hours, % by weight (y_4);
W_{24} – water absorption in 24 hours, % by weight (y_5).

Таблица 3: Design and result of experiment

Experiment number	x_1	x_2	Z_1, % bw	Z_2, min.	σ, MPa	Δh_2, %	Δh_{24}, %	W_2, %	W_{24}, %
1	+1	+1	1	13	45,7	18	19	64	80
2	-1	+1	0	13	31,3	17	21	57	72
3	+1	-1	1	9	17,7	17	21	61	77
4	-1	-1	0	9	51,0	18	26	50	66
5	+1	0	1	11	22,9	20	23	62	78
6	-1	0	0	11	21,7	16	19	58	73
7	0	+1	0,5	13	24,3	17	19	59	77
8	0	-1	0,5	9	44,5	19	22	55	71
9	0	0	0,5	11	47,2	18	22	57	71

Experiment №9 was repeated for assumption of random errors. The sample absolute standard deviations of the arithmetic mean (S_j) were: S_1 = 2 МПа, S_2 = 2 %, S_3 = 2 %, S_4 = 6 %, S_5 = 5 %. It was assumed that in other experiments have the same random errors in OSB properties measurements.

With use of Statgraphics Centurion XV software experimental statistical model of OSB properties ($\hat{y}_j$) for Ko-2 design can be obtained only for normalized input parameters as a following polynomial of the second order [3]:

$$\hat{y}_j = b_0 + b_1x_1 + b_2x_2 + b_{12}x_1x_2 + b_{11}x_1^2 + b_{22}x_2^2, \quad (1)$$

with b_0 – free member (regression constant), b_1, b_2, b_{12}, b_{11}, b_{22} – coefficients, responsible for linear, pair and square influence of input parameters; x_1, x_2, – normalized values of input parameters. One of the disadvantages of Ko-2 design is linear correlation between free member and coefficients responsible for square influence of incoming parameters [3].

The calculation results and their statistical analysis performed by Statgraphics Centurion XV software with a confidence of 0.95 gave absence of incoming parameters influence on all OSB properties measured.

Classical regression analysis [20] is probably less precise in estimation of technological parameters influence on object properties [3], but it allow to obtain practically useful regression equations with free member or without it also for natural values of input parameters:

$$\hat{y}_j = B_0 + B_1Z_1 + B_2Z_2 + B_{12}Z_1Z_2 + B_{11}Z_1^2 + B_{22}Z_2^2, \quad (2)$$

$$\hat{y}_j = B_1Z_1 + B_2Z_2 + B_{12}Z_1Z_2 + B_{11}Z_1^2 + B_{22}Z_2^2, \quad (3)$$

In order to check the possibility of probable pair linear correlation between variables in regression equations (equations collinearity) the multi factor analysis of this variables was performed with Statgraphics Centurion XV software and its results are shown in Table 4.

Table 4: Results of variables correlation analysis

Variable	Pirson correlation coefficient(significance level) for variables				
	Z_1	Z_2	Z_1Z_2	Z_1^2	Z_2^2
Z_1	1 (0)	0,0000 (1)	**0,9735** (0)	**0,9608** (0)	0,0000 (1)
Z_2	0,0000 (1)	1 (0)	0,1770 (0,6487)	0,0000 (1)	**0,9986** (0)
Z_1Z_2	**0,9735** (0)	0,1770 (0,6487)	1 (0)	**0,9353** (0,0002)	0,1768 (0,6491)
Z_1^2	**0,9608** (0)	0,0000 (1)	**0,9353** (0,0002)	1 (0)	0,0000 (1)
Z_2^2	0,0000 (1)	**0,9986** (0)	0,1768 (0,6491)	0,0000 (1)	1 (0)

The correlation analyses for all variables and every parameter of OSB board and calculation of individual correlation coefficients was also done with this software [2] (Table 5).

Table 5: Results of variables correlation analyses with OSB properties

Board properties	Individual correlation coefficients (significance levels) foe variables				
	Z_1	Z_2	Z_1Z_2	Z_1^2	Z_2^2
σ	-0,5958 (0,2891)	-0,3575 (0,5547)	0,7106 (0,1785)	-0,3843 (0,5231)	0,2947 (0,6303)
Δh_2	-0,1719 (0,7823)	0,1381 (0,8247)	0,3586 (0,5534)	-0,1782 (0,7743)	-0,1782 (0,7743)
Δh_{24}	-0,3656 (0,5451)	-0,0673 (0,9144)	0,3105 (0,6111)	0,1522 (0,8070)	0,0000 (1)
W_2	0,5009 (0,3901)	0,5809 (0,3044)	-0,5262 (0,3623)	0,5893 (0,2958)	-0,5040 (0,3866)
W_{24}	0,3857 (0,5214)	0,1537 (0,8051)	-0,3373 (0,5788)	0,4107 (0,4922)	-0,0562 (0,9285)

Than a multifactor regression analysis was performed with Statgraphics Centurion XV for 0.95 confidence with a consecutive exclusion of insignificant members from regression equation.

For more precise estimation of input factors influence on OSB properties the members with coefficients for collinear variables (Table 4) were excluded from statistical analyses considering minimum values of individual linear correlation coefficients for this variables (Table 5).

For the confidence of 0.95 the best from appropriate (significance level less than 0.05 for Fisher distribution) regression equations were chosen equations with a normalized determination coefficient ($R_н^2$) at least 0.9 and minimal sample standard deviation of excesses (standard deviation [1]). Selected best regression equations for investigated composites and their statistical parameters are shown in Table 6.

Table 6: Statistical parameters of obtained regression equations adequate at 0.95 confidence

OSB propertie	Regression equation	Normalized determination coefficient $R_н^2$	Sample excess standard deviation
Bending strength over the board main axis, MPa	$\sigma = 3{,}01Z_2$	0,729	14,7
Swelling by thickness after 2 hours in water, %	$S_2 = 1{,}6Z_2$	0,970	3
Swelling by thickness after 24 hours in water, %	$S_{24} = 1{,}9Z_2$	0,950	5
Water absorption in 2 hours, % by weight	$W_2 = 5{,}2Z_2$	0,984	8
Water absorption in 2 hours, % by weight	$W_{24} = 6{,}6Z_2$	0,983	10

It can be concluded from data in Table 6 that with a confidence taken for factor space all OSB board properties are influenced only by hot pressing time. For hot pressing time increase from 9 to 13 minutes bending strength in boards improves while water repelling properties fail.

Conclusion

The results obtained in this study showed good opportunities of Statgraphics Centurion XV software for evaluating regression mathematical models for laboratory crafted OSB samples describing tendencies of technological parameters influence on OSB properties. Regression models that can be obtained after their confirmation in actual production can be used for forecasting of OSB boards properties and their quality menagment.

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