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MODELING AND OPTIMIZATION OF THE FORCE FRACTURE OF PLYWOOD UNDER THE ACTION OF COMPRESSIVE FORCE

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ABSTRACT
In the wooden walls and similar structures plywood are used for panel. In this structure they are burdened by the force due to action of compressive force on the contact surfaces between the two panels. The optimal choice of type of plywood and its properties play a significant role in determining the scope usage. Applied plywood should meet the design requirements for a particular use.
In order to determine the optimal type and properties of plywood has been done experimental investigation with three types of plywood (beech, poplar, and combined (beech–poplar) and five thickness plywood (18, 20, 25, 30 and 32 mm). Based on the obtained data was done by mathematical modelling of force fracture under the action of compressive force and for conditions a specific type of use is optimized type of plywood and the properties of plywood.
The paper will present the data of experimental investigation of force fracture, mathematical modelling and optimization of force fracture under the action of compressive force.
Keywords: force fracture of plywood, modelling, optimization

1. INTRODUCTION
Plywood is used for a panel of the walls or floors structure. Wooden structure should be resist wind or earthquake activity on them for during time usage. The usual method of construction of wall construction for residential construction is to fastening the plywood to the timber frame with metal fasteners. Plywood and fasteners should resist load effects on wall construction. Eurocode EC 5 was proposed several rules for the construction of diaphragm wall:
- the top of individual panels should be linked by a member or construction across the panel joints;
- if wall is comprised of one or more panels, every panels when joined together to form a wall should be able resist overturning and sliding forces by anchorage to the supporting structure or permanent actions applied to the wall or combination of booth effects;
- the required vertical connection strength between two panels should be $\geq$ 2.5 [kN / m '].

When designing and constructing the diaphragm wall is necessary to choose the type of plywood with exactly defined properties that will be able to withstand all loads in the build and use of wall or floor construction without unwanted deformations.

2. MODELING FRACTURE FORCE PLYWOOD UNDER THE ACTION OF COMPRESSIVE FORCE
The maximum force - force fracture F_{max} of the plywood depends on: density of board ρ_p , thickness of board h_p, humidity of board w_p , types of adhesives, elastic of board E_p, characteristic of the veneer which is constructed the plywood (type of wood, moisture of veneer w_f, veneer thickness d_f, quality - errors veneer), construction of panels (stacking modes of veneer with respect to the angle formed by grain adjacent sheets of veneer α_{vl}, with respect to type of wood and with respect to the thickness of veneer), production technology: specific pressure of pressing pspr, temperature of pressing, the

structural characteristics of presses and other production equipment and the geometric size of the measurement equation. All these factors don't have the same effect on the value of the force fracture.

The testing of floor and wall structures in real conditions of use under the action of loads of different intensity and different environmental conditions showed that the thickness and density of the board directly affect the value of the force fracture. To determine the influence of thickness and density of plywood on the value of the force fracture was conducted experimental research.

Applying rotatable experiment plan and getting a variable for the independent variable: thickness board h and board density ρ, and other influential facrors on the value of force fracture (listed earlier) for the constants, is made the matrix plan experiments.

For the purposes of experimental testing have produced 3 types of plywood: poplar's plywood thickness 20, 25 and 30 mm thick beech's plywood, 20, 25 and 30 mm and combined (beech and poplar) plywood thickness 18, 25 and 32 mm.

The testing of the force fracture of plywood under the action of compressive force was carried out at hydraulic presses HPM 3000 in accordance with EN 789. Matrix plan of experiment and measurement results obtained are shown in Table 1

Table 1. Matrix plan of experiment and measurement results

Number of experiments	Type of plywood	Manufacturing process variables		Coded values of factors - matrix plan						Output values		
		thickness *h* *[mm]*	density *ρ* *[kg/m³]*							*force fracture [kN]*		
										coded value	the measured values	
		x_1	x_2	X_0	X_1	X_2	X_1X_2	X_1^2	X_2^2	y_i	$F_{\max,c,II}$	$F_{\max,c,\perp}$
1	P	20	554	1	–1	–1	1	1	1	y_1	86.06	79.00
2		30	554	1	1	–1	–1	1	1	y_2	126.73	117.25
3	B	20	728	1	–1	1	–1	1	1	y_3	120.53	121.01
4		30	728	1	1	1	1	1	1	y_4	177.70	174.39
5	C	25	641	1	0	0	0	0	0	y_5	137.73	106.05
6		25	641	1	0	0	0	0	0	y_6	136.30	99.40
7		25	641	1	0	0	0	0	0	y_7	133.80	94.60
8		25	641	1	0	0	0	0	0	y_8	145.80	96.25
9		25	641	1	0	0	0	0	0	y_9	144.93	104.65
10		32	641	1	1.414	0	0	2	0	y_{10}	178.20	132.09
11		18	641	1	–1.414	0	0	2	0	y_{11}	101.84	71.05
12		25	764	1	0	1.414	0	0	2	y_{12}	148.49	153.06
13		25	518	1	0	–1.414	0	0	2	y_{13}	106.21	99.39
Coefficient of multiple regression				b_0	b_1	b_2	b_{12}	b_{11}	b_{22}			
Mathematical model				$Y = b_0X_0 + b_1X_1 + b_2X_2$								
				$Y = b_0X_0 + b_1X_1 + b_2X_2 + b_{12}X_1X_2 + b_{11}X_1^2 + b_{22}X_2^2$								

* P – poplar's plywood; B – beech 's plywood; C – combined plywood

Based on the obtained data was carried out mathematical modeling of fracture force and obtained the following mathematical models:

- The force fracture of plywood under the action of compressive force parallel to the grain direction of the surface veneer Y_{cII}:

$$\mathbf{Y_{cII}=139.712 + 25.72663X_1 + 18.15299X_2 + 4.125X_1X_2 - 1.43308X_1^2 - 7.76808X_2^2} \quad (1)$$

- The force fracture of plywood under the action of compressive force perpendicular to the grain direction of the surface veneer $Y_{c\perp}$:

$$\mathbf{Y_{c\perp}=100.19 + 22.24257X_1 + 21.87992X_2 + 3.7825X_1X_2 + 2.84902X_1^2 + 15.17653X_2^2} \quad (2)$$

Checking the significance of the coefficients b_i, b_{im}, b_{ii} was performed according to the Student's criteria and were obtained the regression coefficients and estimate of the significance of mathematical models (1) and (2). The data obtained are presented in Table 2 and 3.

Table 2. The regression coefficients and estimate of the significance of the mathematical model (1) and a mathematical model (2)

Coefficients b_0 , b_i , b_{ii} , b_{ij}	Coefficients a_{ij}	Dispersion of the zero point S_0^2	Dispersion coefficients of regression S_{bi}	The calculated values the t - criteria t_{ri}	Table value *t(4;0,05)*	Ver.
For mathematical model (1)						
b_0 = 139.712	a_{11} = 0.200	28.70327	S_{b0} =2.39596	t_{r0} = 58.31134	2.13	*
b_1 = 25.72663 b_2 = 18.15299	a_{12} = 0.125	28.70327	S_{bi} = 1.89417	t_{r1} = 13.58195 t_{r2} = 9.58357	2.13	* *
b_{12}= 4.125	a_{13} = 0.250	28.70327	S_{b12} =2.67877	t_{12} = 1.53988	2.13	–
b_{11}= –1.43308 b_{22}= –7.76808	a_{14} = 0.14375	28.70327	S_{bii} = 2.03092	t_{r11} = 0.70562 t_{r22} = 3.82489	2.13	– *
For mathematical model (2)						
b_0 = 100.19	a_{11} = 0.200	25.40675	S_{b0} =2.25418	t_{r0} = 44.44622	2.13	*
b_1 =22.24257 b_2 =21.87992	a_{12} = 0.125	25.40675	S_{bi} = 1.78209	t_{r1} = 12.48117 t_{r2} =12.27768	2.13	* *
b_{12}= 3.7825	a_{13} = 0.250	25.40675	S_{b12} =2.52025	t_{12} =1.50084	2.13	–
b_{11}=2.84902 b_{22}=15.17653	a_{14} = 0.14375	25.40675	S_{bii} = 1.91074	t_{r11} =1.49105 t_{r22} =7.94272	2.13	– *

*Significant coefficient of the mathematical model

Taking into account only the significant coefficients encoded mathematical models for Y_{cII} or $Y_{c\perp}$ are:

$$\mathbf{Y_{cII} = 139.712 + 25.72663X_1 + 18.15299X_2 - 7.76808X_2^2} \qquad (3)$$

respectively

$$\mathbf{Y_{c\perp} = 100.19 + 22.24257X_1 + 21.87992X_2 + 15.17653X_2^2} \qquad (4)$$

The adequacy of the model is verified and the F-criterion is determined by multiple regression coefficient R. The results verify the adequacy of mathematical models (3) and (4) are shown in Table 3.

Table 3 Checking the adequacy of mathematical models (3) and (4)

	For mathematical model (3)	For mathematical model (4)
The value of dispersion adequacy S_a^2	84.55265	132.3623
The sum of squares, respectively error experiments S_0^2	114.81310	101.62700
Number of degrees of freedom that relates to the adequacy f_a	3	3
Number of degrees of freedom f_0	4	4
$F_a(f_a,f_0)$	1.76745	5.20972
Table value F – distribution $F_t(f_1,f_2)$	6.59	6.59
Adequacy requirement $F_a<F_t$	satisfy	satisfy
Multiple regression coefficient R	R = 0.97856	R = 0.97425

With checking the adequacy of the model and determination of the coefficients of multiple regression showed that the mathematical models (3) and (4) adequately and sufficiently accurately and reliably describe the dependence of the forces fracture of plywood under the action of compressive force parallel and perpendicular to the direction of wood grain veneer surface. Decoding the mathematical model using the following relation:

$$X_1 = \frac{x_1 - x_{01}}{\frac{x_{1\max} - x_{1\min}}{2}} = \frac{x_1 - x_{01}}{\Delta x_1} = \frac{x_1 - 25}{5} = \frac{h - 25}{5} \text{ and } X_2 = \frac{x_2 - x_{02}}{\frac{x_{2\max} - x_{2\min}}{2}} = \frac{x_2 - x_{02}}{\Delta x_2} = \frac{x_2 - 641}{87} = \frac{\rho - 641}{87} \qquad (5)$$

obtained the final forms of mathematical models to calculate the force fracture of plywood under the action of compressive force parallel and perpendicular to the direction of wood grain veneer surface:

$$F_{\max,c,\text{II}} = -544.357 + 5.14532 \cdot h + 1.52437 \cdot \rho - 0{,}00103 \cdot \rho^2 \quad (6)$$

$$F_{\max,c,\perp} = 651.6235 + 4.44851 \cdot h - 2.31903 \cdot \rho + 0.00200 \cdot \rho^2 \quad (7)$$

3. OPTIMIZATION OF THE FORCE FRACTURE OF PLYWOOD UNDER THE ACTION OF COMPRESSIVE FORCE PARALLEL AND PERPENDICULAR TO THE DIRECTION OF WOOD GRAIN VENEER SURFACE

Plywood, which are thinner and less density have a lower cost to market. Also, they plywood less loading on other elements of wooden structures.

Considering the techno-economic conditions and the recommendations of Eurocode 5 (given in chapter 1), if we want to choose the type of plywood with optimal performance, it is necessary to determine the minimum value of the force fracture of plywood for certain limits, i.e. the objective function of optimization of the force fracture plywood under the action of compressive forces should be taken:

$$F_{cilja} = F_{\max,c}(h,\rho) \rightarrow \min \quad (9)$$

with the following limitations:

a) The thickness of plywood $18.0 \leq h \leq 32.0$ mm
b) Density Plywood $518.0 \leq \rho \leq 764.0$ [kg/m3]
c) $\sigma_{d,c} = k_{\text{mod}} \cdot \dfrac{F_c}{k \cdot b \cdot h \cdot y_M} = k_{\text{mod}} \cdot \dfrac{F_c}{b \cdot h \cdot y_M} \cdot \dfrac{1}{k} \geq \sigma_{dop} = 2500 \cdot \dfrac{1}{k}$ [N/m^2]
d) width of plate elements - the panels $600 \leq b \leq 1220$ [mm] (10)

After searching a large number of combinations obtained values of the objective function and the parameters h and ρ in points:

1. $F_{cilj} = F_{\max,c,\text{II}}(h,\rho) =$ *91.190 [kN]; t*he thickness of plywood *h= 18.9 [mm]* ; density plywood ρ = 582 [kg/m^3] for width of panel *b =0.910 [m]*

2. $F_{cilj} = F_{\max,c,\perp}(h,\rho) =$ *78.698[kN]*; the thickness of plywood *h = 21.9 [mm];* density plywood ρ = 568 [kg/m^3]for width of panel *b =0.910 [m]*

4. CONCLUSION

Based on the above said, it can be concluded the following:

- Force fracture plywood under the action of compressive force parallel to the direction of wood grain on the basis of experimental research has been in the range of 86.06 [kN] for poplar plywood thickness 20 mm to 177.70 [kN] for beech plywood 30 mm thick.
- Force fracture plywood under the action of compressive force perpendicular to the direction of wood grain on the basis of experimental research has been in the range of 79.0 [kN] for poplar plywood thickness 20 mm to 174.39 [kN] for beech plywood 30 mm thick.
- Mathematical modeling has confirmed that the fracture force of plywood under the action of compressive force parallel / perpendicular to the direction of grain depends on the thickness and density plywood.
- This dependence is not linear and can be functionally expressed in mathematical terms (6) and (7).
- Optimizing the mathematical models by defined limitations determined type plywood (combined plywood) with characteristic properties (density and thickness) that can be applied to the floor and wall constructions.

5. REFERENCES

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