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MODELING AND OPTIMIZATION OF FORCE FRACTURE OF PLYWOOD UNDER THE ACTION OF BENDING FORCES

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ABSTRACT

Plywood is most commonly used in manufacture of furniture and building wooden structures such as panels in the floor, roof, wall structures, but also for interior decoration of shell ridges and complex sections (I-beams, box-beam).

When designing structures, it is necessary to know the expected load with which the structure will be burdened, the properties of the materials used to create the structure, the conditions in which these structures are/will be used, and certain environmental and economic requirements of the design and usage.

Plywood is a laminated material based product which is characterized with high mechanical strength, dimensional stability to influence of moisture, smooth and closed surfaces and regular shapes. Plywood appears on the market in a variety of formats - dimensions, depending on the purpose of the respective plywood.

The ability to determine the type of plywood with certain characteristics (physical and mechanical) that are optimal for specific conditions of use, is becoming an imperative in the choice of plywood for use in timber structures.

In applying the floor, roof structures are those exposed to bending forces.

This paper will present the results of experimental studies on value in fracture strength of plywood under the action of shearing forces parallel and perpendicular to the grain direction of surface veneers. In this study we used beech, poplar and combined (beech poplar) plywood thickness of 18, 20, 25, 30 and 32 mm. Based on the obtained data, modeling of fracture force of plywood under the action of shearing forces parallel and perpendicular to the grain direction of surface veneers, and based on certain criteria which simulate the conditions of use of plywood in the structure, application of appropriate programs is carried out to optimize the structure of plywood for the assumed conditions of use .

Key words: plywood, breaking force under the action of shearing forces, modeling, optimization

1. INTRODUCTION

Plywood is commonly used in building wooden structures for panels (decorative or structural) in the ceiling, floor, wall and roof construction, formwork, for the ridges of complex sections (I-beams, box-beam), while designing the interior and the like.

European standards, in particular Eurocode 5, suggest checking the adequacy of the design of the wooden structure as a whole and / or parts of it (and therefore Plywood - Panel) with respect to its bearing capacity, usability and stability of the structure, prior to construction of the wooden structure.

This assessment is based on the concept of limit states and the probability of occurrence of certain standardized load, and it encompasses ultimate limit states and serviceability limit states.

If the plywood is used for stair treads, office shelves,, for lining the floor structures (resilient flooring), for covering the ceiling structure, for covering the roof structures, it is likely to be exposed to bending forces (although it does not exclude the possibility, depending on the design of wooden structure, and operation of other types of loads).

Eurocode 5, EN 12871 and other standards regarding design of wooden construction and testing capacity, stability and usability wooden plate elements in the wooden structure, provide specific recommendations on the characteristics of plywood, based on the dependence of flexural strength values and parameters of constructing wooden structures (ranges between supports, types of loads, etc.).

Based on data from literature (from plywood manufacturers, designers of wooden structures, tests - of timber structures by some test centers) are recommended to determine thickness and density of plywood to certain terms and conditions.

If the plywood used as a bearing element of the structure is exposed to bending, then it is required to be with higher thickness and/or density. However, bearing in mind that built plywood in the structure with its own weight burdens on other structural elements and influences their carrying capacity, and therefore it is necessary to choose plywood with definite thickness and density that will be able to handle the load to which it is exposed at all times and to serve the structure, at the same time keeping itself , its weight, the less strain on other elements of the structure.

On the other hand, it is known that the price of plywood depends on its thickness and density, i.e. plywood with greater thickness and / or density has a higher cost, so there is a significant economic effect in determining the optimal type of plywood with definite certain traits, not better or weaker than what is necessary, related to the cost of the wooden structure.

Since the ultimate limit states scrutinize the situation immediately preceding the fracture or state similar to fracture in sectional structure of the element or compound, loss of stability or material fatigue, when selecting the type of plywood and its properties, considering it as plate element of the wooden structure, it is important to know the value of maximum force - fracture force Fmax, in order to provide more accurate determination of the characteristic values of strength.

The maximum force - the fracture force of plywood Fmax - depends on: the density ρp of plates, plate thickness hp, humidity wp of plates, adhesives, elastic plates epic, veneers feature of which is the plywood is made (wood species, moisture wf of veneer, veneer thickness df, quality - mistakes veneer), construction panels (ways of stacking sheets of veneer with respect to the angle formed by the fibers of adjacent sheets of veneer αvl, ways of stacking sheets of veneer with respect to the type of wood and with regard to the thickness of the veneer), production technology (specific pressure pspr pressing, pressing temperature TPR , the structural characteristics of presses and other production equipment) and the geometric size of the measurement equation.

Plywood that is made from wood veneer of higher density usually has higher values of mechanical properties. Based on data from literature, it is known that with certain structure of plywood veneer from two types of wood with different density (mild to severe wood), it is possible to reach values of mechanical properties that are higher than expected , provided that wood density is taken as an indicator of the value of mechanical properties.

Considering the actual technical and technological capabilities, a test target in experimental research has been defined for testing the influence of thickness and density of plywood, as input parameters in the production of plywood, the fracture force by the force of bending parallel and perpendicular to the fiber direction of the veneer surface, and based on the analysis of experimental data, drafting the proposal - a model of optimal type of plywood for a wide range of applications in building structures.

The purpose of the plan of the experiment was to generate a mathematical model or equations which describe the dependence of the refractive power of the selected factors (density and thickness of plywood). If the factors studied in the experiment are those that affect the value of fracture plywood, and if the data obtained experimentally is acceptable with respect to accuracy and precision, then it will be possible to draw up a proposal - a model of optimal type of plywood that has mechanical properties suitable for wide application in industry. Since the data obtained by experiment showed dependence of fracture force of plywood on thickness and density, it was possible to develop a mathematical model of the fracture force of plywood under the action of shearing forces parallel and perpendicular to the grain direction of the surface veneer, and by defining certain conditions for use of plywood in the structure as limitting, conditions, accompanied by designing a specific computer program, it was possible to execute optimization of the type and to select the appropriate plywood.

2. MATERIAL AND METHODS

Of all the parameters that affect the value of fracture of independent parameters, those taken into consideration are panel thickness and density of the panel, while the other variables that influence the value of fracture plywood are considered as constants.

In this experiment, a central composite rotatable design was used, which is a special form of central composite plan and it is often used in modeling and adaptive control of processes with multiple variables. The total number of trials in this experiment was determined by two independent parameters. The physical and coded values of the parameters varied in five levels. We performed a matrix plan of the experiment (Table 1), and measures to ensure necessary resources for checking the validity of fracture force.

***Table 1**. Matrix Plan experiment*

The number of experi-ments	**Variables manufacturing process**		**Coded values of factors - Matrix Plan**						**Output**
	thickness h [mm]	**density ρ [kg/m³]**							**Breaking force F_{max} [kN]**
	x_1	x_2	X_0	X_1	X_2	X_1X_2	X_1^2	X_2^2	y_i
1	20	554	1	–1	–1	1	1	1	y_1
2	30	554	1	1	–1	–1	1	1	y_2
3	20	728	1	–1	1	–1	1	1	y_3
4	30	728	1	1	1	1	1	1	y_4
5	25	641	1	0	0	0	0	0	y_5
6	25	641	1	0	0	0	0	0	y_6
7	25	641	1	0	0	0	0	0	y_7
8	25	641	1	0	0	0	0	0	y_8
9	25	641	1	0	0	0	0	0	y_9
10	32	641	1	1.414	0	0	2	0	y_{10}
11	18	641	1	–1.414	0	0	2	0	y_{11}
12	25	764	1	0	1.414	0	0	2	y_{12}
13	25	518	1	0	–1.414	0	0	2	y_{13}
Coefficient of multiple regression			b_0	b_1	b_2	b_{12}	b_{11}	b_{22}	
Mathematical Model			$Y = b_0X_0 + b_1X_1 + b_2X_2$						
			$Y = b_0X_0 + b_1X_1 + b_2X_2 + b_{12}X_1X_2 + b_{11}X_1^2 + b_{22}X_2^2$						

For the purpose of this experimental research, the three types of waterproof sanded plywood were as follows:

- Beech plywood thickness d = 20, 25 and 30 mm;
- Poplar plywood thickness d = 20, 25 and 30 mm and
- Combined (beech and poplar) plywood thickness d = 18, 25 and 32 mm.

Plywood was produced in the "Novi Drvni Kombinat” in Sremska Mitrovica by conventional manufacturing process manufacturers who used their technical and technological equipment and applied as manufacturers the technological parameters (specific pressure pressing, temperature plate presses), as well as the manufacturer's glue (melamine - urea formaldehyde glue).

The set up of the panels was as follows:

– For poplar plywood:

⊖ 20 mm thick is:

I –I –I –I –I i.e. 2.5 +*2.5*+2.5 +*2.5*+2.5 +*2.5*+2.5 +*2.5*+2.5 mm

⊖ 30 mm thick is:

I –I –I –I –I –I –I –I i.e.

2.0 +*2.5*+2.0+*2.5*+2.0+*2.5*+2.0+*2.5*+2.0+*2.5*+2.0+*2.5*+2.0+*2.5*+2.0 mm

⊖ 25 mm thick is:

| –| –| –| –| –| i.e. 2.5 +*2.5*+2.5+*2.5*+3.0+*2.5*+3.0+*2.5*+2.5+*2.5*+2.5 mm

– For beech plywood

20 mm thick is:

| – | – | – | – | i.e. 2.5 +*2.5*+2.5 +*2.5*+2.5 +*2.5*+2.5 +*2.5*+2.5 mm

⊖ 30 mm thick is:

| – | – | – | – | – | – | – | i.e. 2.0 +*2.5*+2.0+*2.5*+2.0+*2.5*+2.0+*2.5*+2.0+*2.5*+2.0+*2.5*+2.0 + *2.5*+2.0 mm

⊖ 25 mm thick is:

| – | – | – | – | – | i.e. 2.5 +*2.5*+2.5 +*2.5*+2.5 +*2.5*+2.5 +*2.5*+2.5+*2.5*+2.5 mm

⊖ For combined (beech and poplar) plywood

⊖ 25 mm thick is:

| – | – | – | – | – | – | i.e. 2.0 +*2.5*+2.0 +*2.5*+2.0 +*2.0*+2.0+*2.0*+2.0 +*2.5*+2.0+*2.5*+2.0 mm

⊖ 18 mm thick is:

| – | – | – | – | i.e. 2.0 +*2.5*+2.0 +*2.5*+2.0 +*2.5*+2.0 +*2.5*+2.0 mm

⊖ 32 mm thick is:

| – | – | – | – | – | – | – | i.e. 2.1 +*2.5*+2.1 +*2.5*+2.1 +*2.5*+2.5 +*2.5*+2.5 + *2.5* + 2.1 + *2.5* +2.1 + *2.5*+ 2.1 mm

When designing the set up of panel veneer sheets, they were stacked so that the direction of the grain adjacent sheets of veneer was at an angle of 90 °. It was also taken into consideration when designing for combined plywood that beech veneer or poplar accounts for about 50% of the construction.

The specific pressing pressure was calculated as follows:

- For poplar plywood 8 [kg / cm2] = 7.848 [bar] ≈ 8 [bar]
- For Combined Beech - poplar plywood 10 [kg / cm 2] = 9.81 [bar] ≈ 10 [bar]
- For beech plywood 12 [kg / cm 2] = 11,772 [bar] ≈ 12 [bar]

Temperature pressing amounted to 110 ° C.

Density produced plywood averaged:

- Beech plywood ρ = 728 [kg / m 3]
- Poplar plywood ρ = 554 [kg / m 3]
- Combined (beech - poplar) plywood r = 641 [kg / m 3]

In the Ltd "Bor" in Bihac were cut test pieces for experimental testing in fracture strength of plywood under the influence of load bending parallel and perpendicular to the fiber surface veneer, in accordance with the requirements of EN 789 and EN 1058th.

All test pieces were conditioned to constant weight in an atmosphere with a relative humidity of 65 ± 5% and temperature 20 ± 2 ° C.

Testing of the flexural properties panel was made in accordance with EN 789 . The dimensions the test pieces for testing failure force under the action of shearing forces, used in this experimental study of fracture forces under the action of shearing forces parallel and perpendicular to the wood grain of the surface veneer, were:

- for panel of thickness d = 18 mm - dimensions test pieces L x W x H = 926 x 300 x 18 mm
- for panel thickness 20 mm - dimensions test pieces L x W x H = 990 x 300 x 20 mm
- for panel of thickness d = 25 mm - dimensions test pieces L x W x H = 1.150 x 300 x 25 mm
- for panel of thickness d = 30 mm - dimensions test pieces L x W x H = 1.150 x 300 x 30 mm
- for panel of thickness d = 32 mm - dimensions test pieces L x W x H = 1.150 x 300 x 32 mm.

Testing flexural properties of plywood was done at press HPM 3000 with creation of upper and lower attachments attached to the lower and upper plate presses so that the testing could be done in accordance with the requirements of EN 789.

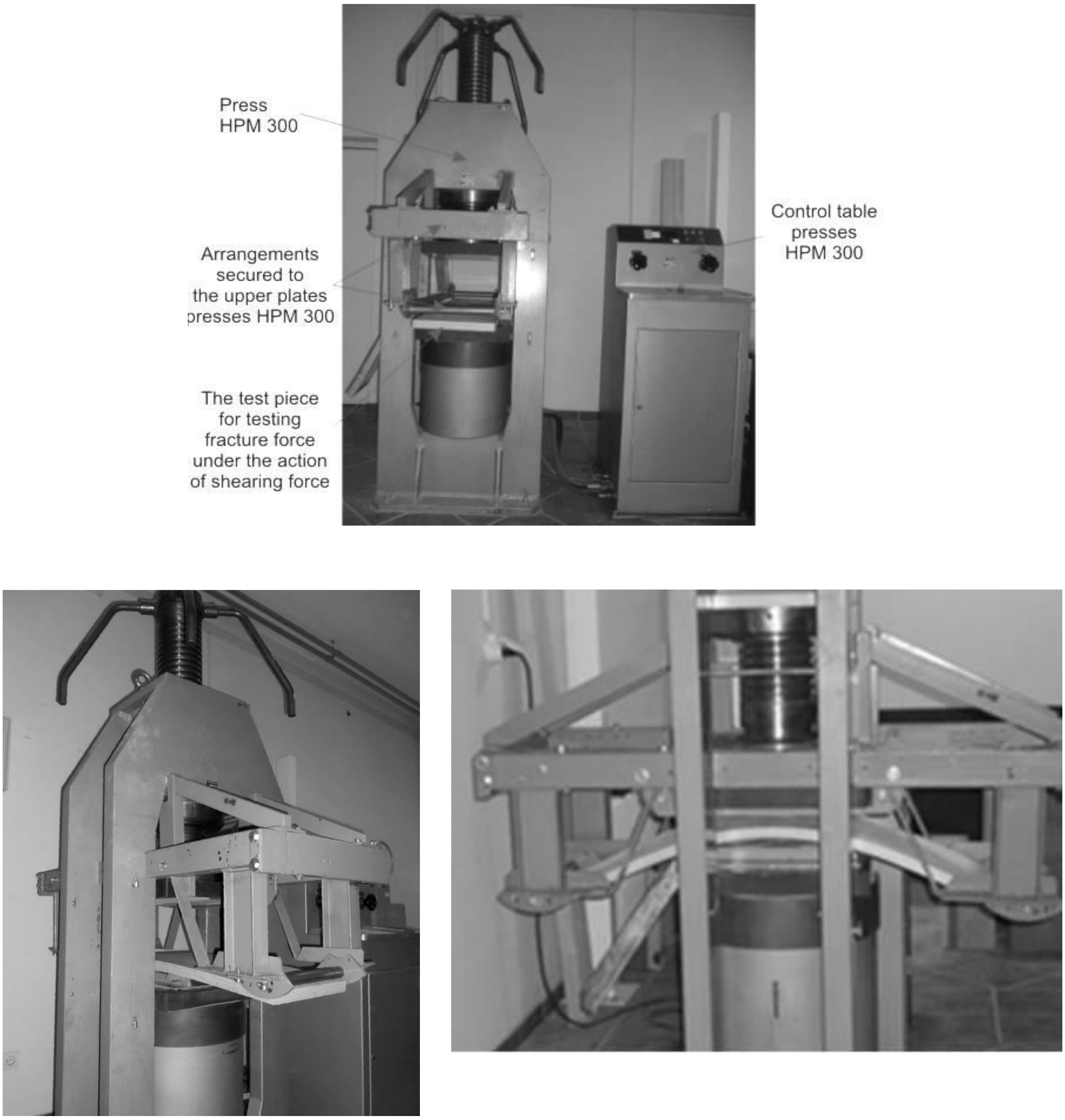

Figure 1. *Test failure force plywood under the action of load (force) bending at press HPM 3000*

The data obtained by experimental tests was used for mathematical modeling of fracture force of plywood under the action of shearing forces parallel and perpendicular to the grain direction of surface veneers.

The process of modeling fracture forces under the action of shearing forces parallel to the fiber direction of the surface veneer plywood $F_{max,\ m,\ II}$, and the process of modeling fracture forces under the action of shearing forces perpendicular to the grain direction of the surface veneer plywood $F_{max,\ m,\ \perp}$, was carried out as follows:

- Calculation of the regression coefficients,
- Checking the homogeneity of the dispersion according to the criteria Cochran,

- Calculated error of the experiment,
- Calculation of the dispersion of the regression coefficients,
- Test of significance to the criterion of the Student,
- Check the dispersion adequacy criteria and Fisher,
- Check the adequacy of the model by the criterion of Fisher and decoding.

Eurocode 5, EN 12871 and other standards during design of wooden structures and testing capacity, stability and usability of wooden plate elements in the wooden structure, provide specific recommendations on the flexure strength. Thus, for example, when using plywood flooring for residential buildings, the requirements are as follows:

- $fm \leq \sigma = 1.5$ [kN/m ^{2}] in operation of the maximum continuous load or
- $fm \leq \sigma = 2.7$ [kN/m ^{2}] at the maximum activity of the concentrated load.

Recommendations for flexural strength and values ranges between supports are used for the process optimization in fracture strength of plywood under the action of shearing forces parallel and perpendicular to the fiber direction of surface veneers. The defined objective function is as follows:

$$F_{cilja} = y(x_1, x_2) = F_{\max, m, II}(h, \rho) \tag{1}$$

$$F_{cilja} = y(x_1, x_2) = F_{\max, m, \perp}(h, \rho) \tag{2}$$

And for the aforementioned functions the following requirement was set:

$$F_{cilja} = F_{\max, m}(h, \rho) \rightarrow \max$$

In the specific area of application of plywood (residential building), the following requirements were set:

a) thickness of plywood $18.0 \leq h \leq 32$ mm;
b) plywood density $554 \leq \rho \leq 728$ [kg / m^3];

c) $$k_{\mathrm{mod}} \times \frac{F_{\max, m} \times \frac{l}{4}}{W_{transf}} \times \frac{1}{y_M} \leq 1.5\left[kN / m^2\right]$$

where:
$k_{mod} = 1.1$ modification factor
$F_{max,\ m}$ - maximum force, breaking force [N]
W_{transf} - section modulus for the ultimate limit state (depending on the thickness and position (orientation) of each veneer panel structure with respect to the direction of the wood fibers)
$y_M = 1.2$ partial safety factor for material properties
d) span between supports $400 \leq l \leq 1220$ [mm]
panel width is 1220 mm.

Optimization of fracture force plywood is performed using the non-linear programming. For purposes of implementation of the optimization process fracture force F_{max} is made available in the Java programming language that defines the limits for optimum thickness h and density ρ.

The Java programming language was used to develop a program for doing the objective functions with step

- for h: h = h + 0.1;
- for ρ: ρ = ρ + 1;
- for b or *l*

b = b + 1
or
l = *l* +1.

After searching a great number of combinations, the values of the objective functions and the parameters h and ρ were obtained.

3. RESULTS AND DISCUSSION

Experimental testing was performed according to the matrix plan of the experiment. For each experiment 8 tests were carried out and the average value of fracture plywood was calculated.

Table 2. *Results of the experiment*

The number of experi-ments N_j	**Variables manufacturing process**		**Coded values of factors - Matrix Plan**						**Experimental value**	
	h [mm]	**ρ [kg/m^3]**	**X_0**	**X_1**	**X_2**	**X_1X_2**	**X_1^2**	**X_2^2**	**Fmax, m,II**	**Fmax, m,⊥**
1	20	554	1	–1	–1	1	1	1	3.03	2.68
2	30	554	1	1	–1	–1	1	1	5.68	4.86
3	20	728	1	–1	1	–1	1	1	5.63	5.23
4	30	728	1	1	1	1	1	1	7.59	7.09
5	25	641	1	0	0	0	0	0	5.70	3.45
6	25	641	1	0	0	0	0	0	6.15	3.18
7	25	641	1	0	0	0	0	0	6.05	3.15
8	25	641	1	0	0	0	0	0	6.38	3.80
9	25	641	1	0	0	0	0	0	5.85	3.90
10	32	641	1	1.414	0	0	2	0	7.55	5.80
11	18	641	1	–1.414	0	0	2	0	4.50	2.50
12	25	764	1	0	1.414	0	0	2	6.80	6.60
13	25	518	1	0	–1.414	0	0	2	3.96	3.35

The data obtained by experimental tests was used for mathematical modeling of fracture force of plywood under the action of shearing forces parallel and perpendicular to the grain direction of surface veneers.

As stated previously, the used central composite rotatable design of plan is a special form of central composite plan and it is often used in modeling and adaptive control of processes with multiple variables. Given the research objective and realistic technical and technological conditions of production of plywood in this study for the independent variable, the following variables were considered:

- panel thickness h and
- density panel ρ depending on the type of wood,

while other factors influencing breaking force Fmax were considered to be constants.

In the modeling process of fracture strength under the action of shearing forces parallel to the direction of grain of the surface veneer plywood $F_{max\ m\ II}$, and in the process of modeling of fracture strength under the action of shearing forces perpendicular to the grain direction of the surface of veneer plywood $F_{max\ m\perp}$, the following results were obtained :

The encoded mathematical model for calculating fracture forces under the action of shearing forces parallel to the grain direction of surface veneers had the following form:

$$Y = 6.026 + 1.11533X_1+1,06572X_2 - 0,38247X_2^2$$

or coded mathematical model for calculating fracture forces under the action of shearing forces perpendicular to the grain direction of surface veneers had the form:

$$Y = 3.496 + 1.08827X_1+ 1.17193X_2 + 0.42381X_1^2 + 0.83631X_2^2$$

The values of the coefficients indicate that the adequacy of mathematical models adequately describe the fracture strength of plywood under the influence of load bending parallel and perpendicular to the direction of the grain surface veneer. In addition, the coefficients of multiple regression indicate sufficiently good interdependence of the mathematical model factors.

Table 3. *Results of modeling in fracture strength of plywood under the action of shearing forces*

	parallel to the grain direction of surface veneers	**perpendicular to the grain direction of surface veneers**
Checking the homogeneity of the dispersion	$K_h = 0.44993 < K_t\ (4,5) = 0.544$ $\alpha = 0.05$	$K_h = 0.34194 < K_t\ (4,5) = 0.544$ $\alpha = 0.05$
Regression coefficients b_0 b_i b_{ii} b_{ij}	$b_0 = 6.026$ $b_1 = 1.11533$ $b_2 = 1.06572$ $b_{12} = -0.1725$ $b_{11} = -0.05997$ $b_{22} = -0.38247$	$b_0 = 3.496$ $b_1 = 1.08827$ $b_2 = 1.17193$ $b_{12} = -0.080$ $b_{11} = 0.42381$ $b_{22} = 0.83631$
Calculated values t - criteria t_{ri}	$t_{r0} = 51.06413 > t(4;0.05) = 2.13$ b_0 significant coefficient $t_{r1} = 11.9551 > t(4;0.05) = 2.13$ b_1 significant coefficient $t_{r2} = 11.42326 > t(4;0.05) = 2.13$ b_2 significant coefficient $t_{12} = 1.30743 < t(4;0.05) = 2.13$ b_{12} insignificant coefficient $t_{r11} = 0.59956 < t(4;0.05) = 2.13$ b_{11} insignificant coefficient $t_{r22} = 3.82362 > t(4;0.05) = 2.13$ b_{22} significant coefficient	$t_{r0} = 22.62985 > t(4;0.05) = 2.13$ b_0 significant coefficient $t_{r1} = 8.91063 > t(4;0.05) = 2.13$ b_1 significant coefficient $t_{r2} = 9.59565 > t(4;0.05) = 2.13$ b_2 significant coefficient $t_{12} = 0.46317 < t(4;0.05) = 2.13$ b_{12} insignificant coefficient $t_{r11} = 3.23647 > t(4;0.05) = 2.13$ b_{11} significant coefficient $t_{r22} = 6.38654 > t(4;0.05) = 2.13$ b_{22} significant coefficient
Adequacy coefficient	$F_a = 1.39964 < F_t = 6.59$ for $\alpha = 0.05$ and $F_t\ (3,4)$	$F_a = 1.12712 < F_t = 6.59$ for $\alpha = 0.05$ and $F_t\ (3,4)$
Coefficient of multiple regression	R = 0.98602	R = 0.98353

The final form of the mathematical model was obtained by decoding (replacing coded values with expressions

$$X_1 = \frac{x_1 - x_{01}}{\Delta x_1} = \frac{h - 25}{5} \quad \text{and} \quad X_2 = \frac{x_2 - x_{02}}{\Delta x_2} = \frac{\rho - 641}{87}$$

performing mathematical operations) and the mathematical model to calculate fracture force under the action of shearing forces parallel to the grain direction of the surface veneer was as follows:

$$F_{\max,\,m,\mathrm{II}} = -28.165 + 0.22306 \times h + 0.07703 \times \rho - 0.00005 \times \rho^2$$

The mathematical model for calculating the fracture force under the action of shearing forces perpendicular to the grain direction of surface veneers was as follwos:

$$F_{\max m,\perp} = 45.41442 - 0.62997 \times h + 0.01695 \times h^2 - 0.12818 \times \rho + 0.00011 \times \rho^2$$

In the process of optimizing the previously mentioned limitations and the application program which is made in the Java programming language, the following results were obtained:

- for breaking force under the action of shearing forces parallel to the grain direction of surface veneers

$$F_{cilj} = F_{max,m,II}(h,\rho) = 5.428\ [kN]$$

respectively: $h = 21.0\ [mm]$
$\rho = 696\ [kg/m^3]$

for $l = 476\ [mm]$

- for breaking force under the action of shearing forces perpendicular to the grain direction of surface veneers

$$F_{cilj} = F_{max,m,\perp}(h,\rho) = 4.438\ [kN]$$

respectively: $h = 22.5\ [mm]$
$\rho = 716\ [kg/m^3]$

for $l = 447\ [mm]$

When applying plywood as structure element that will be exposed to shearing forces in the floor, roof and similar structures, it is proposed that the axial distance between the supports measures within the limits be within the range of 400 to 600 m. If it is not the case, then when trying to identify the type and choice of panels, it is needed, in addition to checking the ultimate limit states, to check the serviceability limit states, as deflections might appear and their size might have an adverse affect on usability of the structure.

Analysis of the resulting optimization solutions in fracture strength of plywood under the action of shearing forces parallel or perpendicular to the grain surface veneer shows that the capacity criterion for bending strength in both selected plywood pieces which is 1.5 [kN / m 2] was met. The proposed axial distance (l = 476 [mm] for plywood that will be exposed to shearing forces parallel to the grain direction of the surface veneer l = 447 [mm] and for the plywood that will be exposed to bending forces perpendicular to the grain surface veneer) is within limits that do not require verification of serviceability limit state, i.e., deflections on plywood during its use, which might affect the usability of this structural element, are not expected.

It can be concluded that the proposed plywood (characteristic ρ = 696 [kg/m ^{3}], h = 21.0 [mm], and ρ = 718 [kg/m ^{3}], h = 22.5 [mm]) satisfy the requirements of design and that the resulting solutions for fracture strength, density and thickness of the panels are optimal solutions, provided that certain plywood was incorporated into the construction of the proposed axial spacing l.

4. CONCLUSIONS

1. Breaking force of plywood under the influence of the force of bending depends on the type of panels and the angle under which the load is placed in relation to the direction of the grain of the surface veneer.
2. Breaking force of plywood under the action of bending force parallel and perpendicular to the wood fiber surface veneer depends on density and thickness.
3. The minimum values of breaking force were in poplar plywood, higher in combinations with plywood and the highest in beech plywood.
4. Also, panels of the same type and the same thickness had an inferiority breaking force in the operation of the load perpendicular to the grain surface veneer than in the parallel operation load vehicle for all types of plywood.

5. The experimental studies confirm the fact that the same value of fracture is present in thinner plywood with higher density and vice versa, plywood with lower density and higher thickness.

6. The dependence of the refractive power density and thickness is not linear and can be described by mathematical models presented.

7. The input parameters of the manufacturing process affect the type and characteristics of plywood. The features of the plywood determine the scope of application.

8. Optimizing input parameters in the production process affects the production of optimal type of plywood certain traits that are suitable (applicable) for a specific application area.

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