INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN, 2/2014 (6): 65–71

TENSILE STRENGTH IN DIFFERENT DIRECTIONS OF LAMINATED PLYWOOD MADE FROM BEECH VENEERS

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ABSTRACT

The aim of the research presented in this paper is to study the tensile properties at different directions of experimental plywood.

For this research nine-layered plywood is made. The model is made from peeled beech veneers with thickness of 1,2; 1,5; 2,2 and 3,2 mm.

Pure water-soluble phenol-formaldehyde resin is used as plywood binder.

The tensile strength of the plywood panel is tested in five directions, i.e., parallel and perpendicular to the face grain, and at the angles of 22,5º; 45º and 67,5º to the face grain of the panel.

Coefficients of the equality of the tensile strength in different directions of the plywood model is calculated trough polar diagram made on the basis of the obtained data for the tensile strength at different angles to the face grain of plywood. The coefficient of mass quality is calculated too.

The research results showed that the experimental plywood model meet and exceed the defined values of tensile strength in accordance with the requirements of the standard for load-bearing plywood for use in construction.

Key words: laminated plywood, beech veneers, tensile strength, coefficient of equality of tensile strength, coefficient of mass quality

INTRODUCTION

Wood composite materials are intensively used in modern construction of wooden buildings. The wide range of wooden composite includes materials for indoor and outdoor application and for structural or non-structural use.

Plywood is one of the major types of wood composite materials for structural use.

Because of its high strength and stiffness to weight ratios, plywood is very cost effective to use in structural applications such as: flooring, siding, roofing, shear walls, formwork and engineered wood products-fabricated beams. Plywood's laminated structure distributes loads from impact over a larger area on the opposite face, which effectively reduces the tensile stress.

The utilization of plywood in modern construction requires a bigger understanding of mechanical characteristics of this material. The tensile strength of plywood is of a particular importance in stress-skin panels and sandwich-type structures in which the plywood facings are the load-bearing members (ASTM Technical publication No. 194). These properties are one of the most important characteristics of plywood that are commonly considered (Kljak and Brezovic, 2007).

In order to produce stable panels with higher physical and mechanical properties that can meet the modern exploitation requirements plywood is constantly subjected to research. Improving of mechanical properties of plywood can be done by changing the positions of veneers in plywood structure (Jakimovska Popovska and Iliev, 2013), as well as by changing the thickness of the outer layers (Kljak et al. 2006).

The research of the characteristics of plywood properties in different directions is important for proper application of these materials as load-bearing panels in different structures in construction (Jakimovska Popovska, 2011).

MATERIALS AND METHODS OF THE EXPERIMENTAL WORK

For the realization of the research experimental plywood with nine layers of beech peeled veneers is made. Plywood is made from two veneer sheets with thickness of 1,2; 1,5 and 2,2 mm and three veneer sheets with thickness of 3,2 mm.

The veneers with thickness of 1,2 and 3,2 mm runs parallel to the longitudinal axis of the panel (parallel to the face grain), while the veneers with thickness of 1,5 and 2,2 mm runs perpendicular to this axis. The central layer of plywood model represents a veneer sheet with thickness of 3,2 mm, while the veneers with thickness of 1,5 mm build the surface layers of the panel. The orientation of adjacent layers in plywood structure is at right angle, which means that the grain direction of the surface layers is parallel to the length of the panel.

The configuration of plywood structure is shown on figure 1.

The panels are overlaid with phenol formaldehyde-resin impregnated paper with a surface weight of 120 g/m^2. The paper is bonded during the hot pressing process. Facing the panel with this resin impregnated paper is made in order to improve the resistance of moisture penetration in plywood.

Pure water-soluble phenol-formaldehyde resin with concentration of 47,10 % is used as plywood binder, applied in quantity of 180 g/m^2.

The panels are pressed in a hot press using the following parameters: specific pressure – P=1,8 MN/m^2; temperature of hot plates – T=155 ºC and pressing time – t=20 min.

Density of the experimental plywood is 759,99 kg/m^3. The panel is made with dimensions of 580×580×17 mm. The humidity of the plywood is 7,98 %.

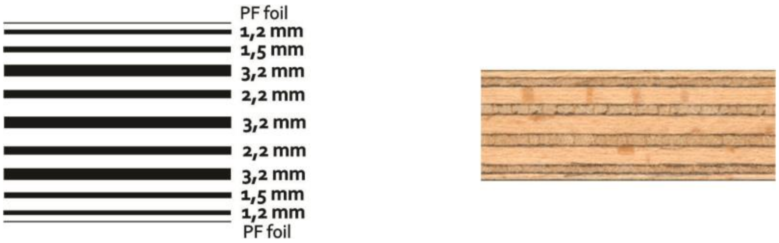


Figure 1: Pattern and cross-section of plywood structure

The tensile strength of plywood panel is tested according to the national standard MKS D.A8.066/85. This property is tested in five directions, i.e., parallel and perpendicular to the face grain, and at the angles of 22,5º; 45º and 67,5º to the face grain of the panel.

On the basis of the obtained data for tensile strength in different directions of plywood panel the coefficient of the equality of the tensile strength of the plywood model is calculated (K_{et}). This coefficient is calculated on the basis of graphic method by inputting the values of tensile strength in polar coordinate system (Fig. 2) and by equation (Krpan, 1971). On polar coordinate system a circle with radius of the highest obtained value of tensile strength is circumscribed. The area under this circle is calculated. The values of tensile strength in all tested direction are imputed in the polar system and connected to each other so they make a diagram with certain area that is calculated too. The ratio between the area under the diagram and the area under the circle represent the coefficient of equality of the tensile strength of plywood (Eq. 1).

The curves of the diagram that are obtained by this kind of tests are symmetrical in all four quadrants of the polar coordinate system, so it is satisfactory to test the tensile strength of plywood only in one quadrant and mirrored it in other three quadrants (Krpan, 1971).

$$K_{et} = \frac{A_d}{A_c} \tag{1}$$

where, A_d – area under the diagram; A_c – area under the circle with radius of the highest obtained value of tensile strength.

The curves of the diagram that are obtained by this kind of tests are symmetrical in all four quadrants of the polar coordinate system, so it is satisfactory to test the tensile strength of plywood only in one quadrant and mirrored it in other three quadrants (Krpan, 1971).

The coefficient of equality of the tensile strength (K_{et}) and the coefficient of mass quality (K_{mq}) defines the quality and usability of plywood panel.

The coefficient of mass quality (K_{mq}) is calculated by the following equation:

$$K_{mq} = \frac{\sigma_{t\parallel} + \sigma_{t\perp}}{\gamma} \tag{2}$$

where, $\sigma_t\parallel$ – tensile strength parallel to the face grain of the plywood panel; $\sigma_t\perp$ – tensile strength perpendicular to the face grain of the plywood panel; γ – plywood density.

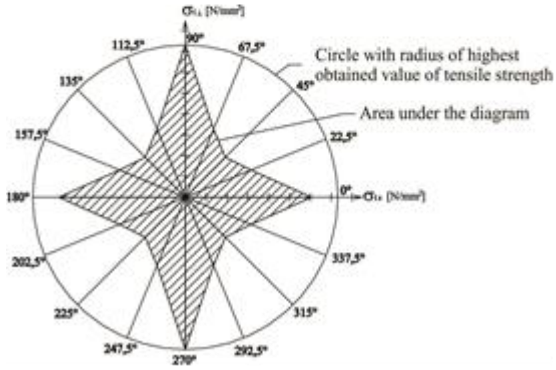


Figure 2. Graphic method for determination of coefficient of equality of tensile strength of plywood

RESULTS AND DISCUSSION

The results from the research of the tensile strength of experimental plywood are shown in table 1 and on figures 3 and 4.

Table 1. Statistical data for the tensile strength in different directions of plywood panel

Orientation of the test specimens to the face grain of the panel	Number of test specimens	X_{min} [N/mm²]	X_{max} [N/mm²]	X_{mean} [N/mm²]	$X_{mean} \pm f_{xmean}$ [N/mm²]	$S \pm f_S$ [N/mm²]	$V \pm f_v$ [%]
ǁ	5	76,32	83,50	80,51	80,51±1,22	2,74±0,87	3,40±1,07
⊥	5	54,96	60,44	57,73	57,73±0,88	1,97±0,62	3,41±1,08
∡22,5°	5	34,21	36,64	35,50	35,50±0,56	1,13±0,40	3,18±1,12
∡45°	5	24,67	27,51	25,90	25,90±0,57	1,28±0,40	4,94±1,56
∡67,5°	5	35,01	37,09	36,04	36,04±0,43	0,97±0,31	2,69±0,85

The analysis of the obtained test results of tensile strength in different directions of plywood (Tab. 1, Fig. 3 and 4) showed that the highest value of this property is achieved parallel to the face grain of the panel, while the lowest value of 25,90 N/mm² is achieved at the angle of 45º to the face grain of the plywood panel. The tensile strength perpendicular to the face grain of the panel is lower than the value parallel to the face grain for 28,29 %, but higher than the values at the angle of 22,5º, 45º and 67,5º to the face grain for 62,62 %, 122,89 % and 60,18% respectively.

The difference between the values of tensile strength at the angels of 22,5º and 67,5º is very small. These two values are almost equal. The tensile strength at the angle of 67,5º is higher than the value of this property at the angle of 22,5º for 1,52 %.

The differences in the values of tensile strength in different directions of plywood panel are a result of the orientation of the wood fibers in plywood structure in relation to the direction of the action of tensile force. That means that the orientation of the veneers in plywood structure has direct impact on plywood tensile strength.

The tensile strength of wood is higher in direction of the wood fibers. By increasing the angle between the wood fibers and direction of the tensile force, the tensile strength of wood is decreasing. At the angles between 60º and 90º, the tensile strength of wood is almost equal to the tensile strength perpendicular to the wood fibers (Likić-Simonović, 1983).

The veneers with thickness of 3,2 mm in experimental plywood occupy the biggest percentage of the thickness of the plywood panel, so the value of tensile strength depends on its orientation to the direction of the tensile force. The orientation of these veneer sheets is parallel to the face grain of the panel, which results with highest value of the tensile strength in this direction of plywood panel.

The failure mode of the test specimens for determination of the tensile strength is showen on figure 5. The visual analysis of the test specimens during testing the tensile strength showed that the failure of the test specimens happens at once, whitout prior delamination of the veneeres.

The force-stroke diagrams during testing of tensile strength showed that the failure of the material happened at once without significant plastic deformation.

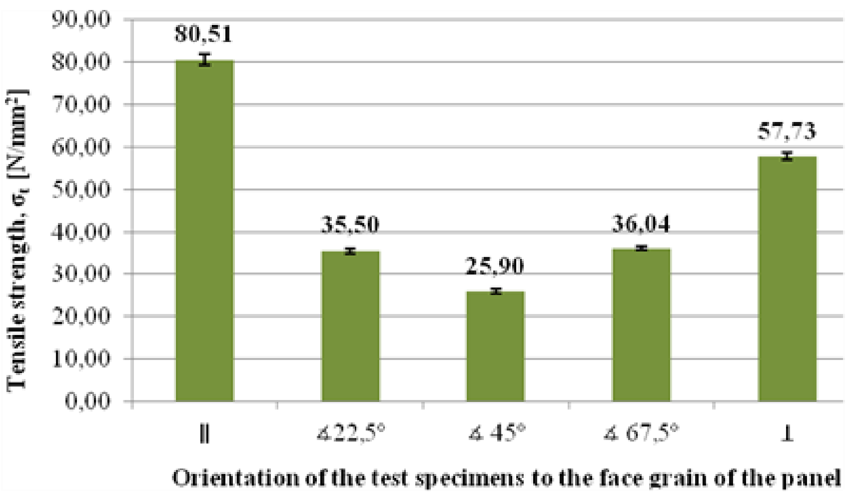


Figure 3: Results from the test of tensile strength in different directions of plywood panel

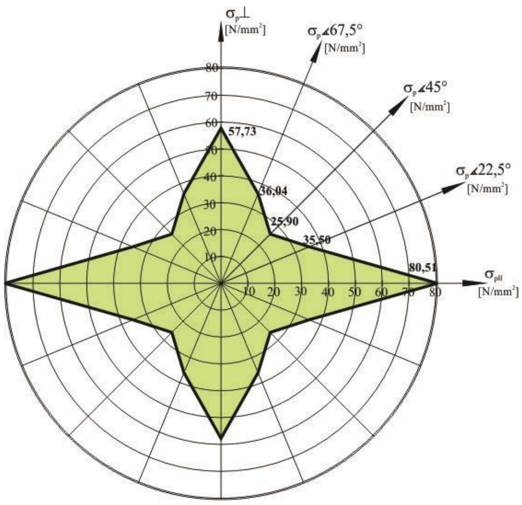
The national standard MKS D.C5.043 for load-bearing plywood for use in construction defines the minimal values of tensile strength of 24 N/mm^2 parallel to the face grain; 12 N/mm^2 perpendicular to the face grain and 6 N/mm^2 at the angles of 30 and 60º to the face grain of the plywood panel. The experimental plywood exceeds these values in all tested directions of the panel.

The obtained values of plywood tensile strength are within the limits of the values for this property listed in available literature. Nikolić (1988) for five-layer beech plywood gives the values of 71,1 N/mm^2 for tensile strength parallel to the face grain of the panel, 62,5 N/mm^2 for tensile strength perpendicular to the face grain and 22,2 N/mm^2 for tensile strength at the angle of 45º to the face grain of the plywood panel.

Arriga and Peraza (2004) for pine plywood with thickness of 15 and 18 mm gives the values of 22,3 and 19,5 N/mm^2 for tensile strength parallel to the face grain and the values of 15,0 and 17,5 N/mm^2 for tensile strength perpendicular to the face grain of the panel.

Brezović *et al.* (2002) gives the values of 49,12 and 28,63 N/mm^2 for tensile strength parallel and perpendicular to the face grain of poplar plywood. The same authors (Brezović *et al.*,2002) for reinforced poplar plywood with carbon fibers gives the values of 97,88 N/mm^2 for tensile strength parallel to the face grain and 70,97 N/mm^2 for tensile strength perpendicular to the face grain of the panel.

Kljak and Brezovic (2007) gives the values of 18,41 and 27,20 N/mm^2 for tensile strength parallel and perpendicular to the face grain of seven-ply plywood made of okume veneers.



K_{et} = 0,26; Kmq = 1855

Figure 4: Polar diagram of plywood tensile strength

The coefficient of equality of the tensile strength (K_{et}) is 0,26, while the coefficient of mass quality is 1855. The values of these coefficients are within the limits of the values listed in the available literature. Nikolić (1988) for beech plywood with thickness of 6 and 5 mm gives values of 1494 and 2135 for the coefficient of mass quality. Krpan (1971) for beech plywood with thickness of 5 mm gives values the coefficient of equality of the tensile strength within the limits of 0,063 to 0,308.

Brezović *et al.* (2002) gives the values of 1500 for the coefficient of mass quality for poplar plywood and 2500 for poplar plywood reinforced with carbon fibers.

From the value of the coefficient of mass quality the values of the properties of the material in relation to its density can be seen. The increasing of this coefficient speaks for increasing of the quality of plywood structure. As comparison, the coefficient of the mass quality of steel is 1026 (Nikolić, 1988).

The force-stroke diagrams during testing of tensile strength of plywood are shown on figure 6.

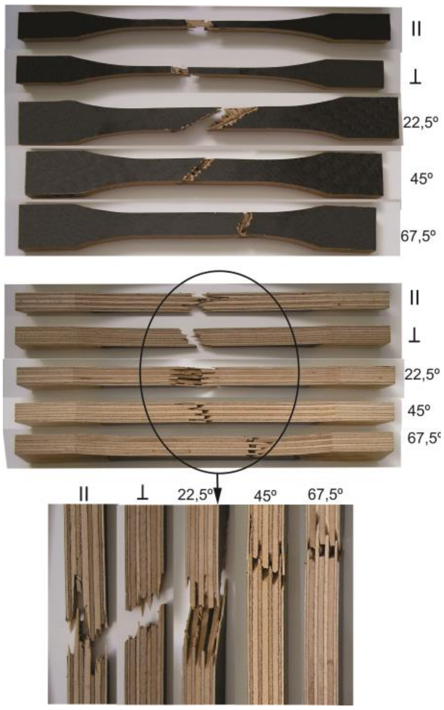


Figure 5: Faliure mode of the test specimens for determination of tensile strength of plywood

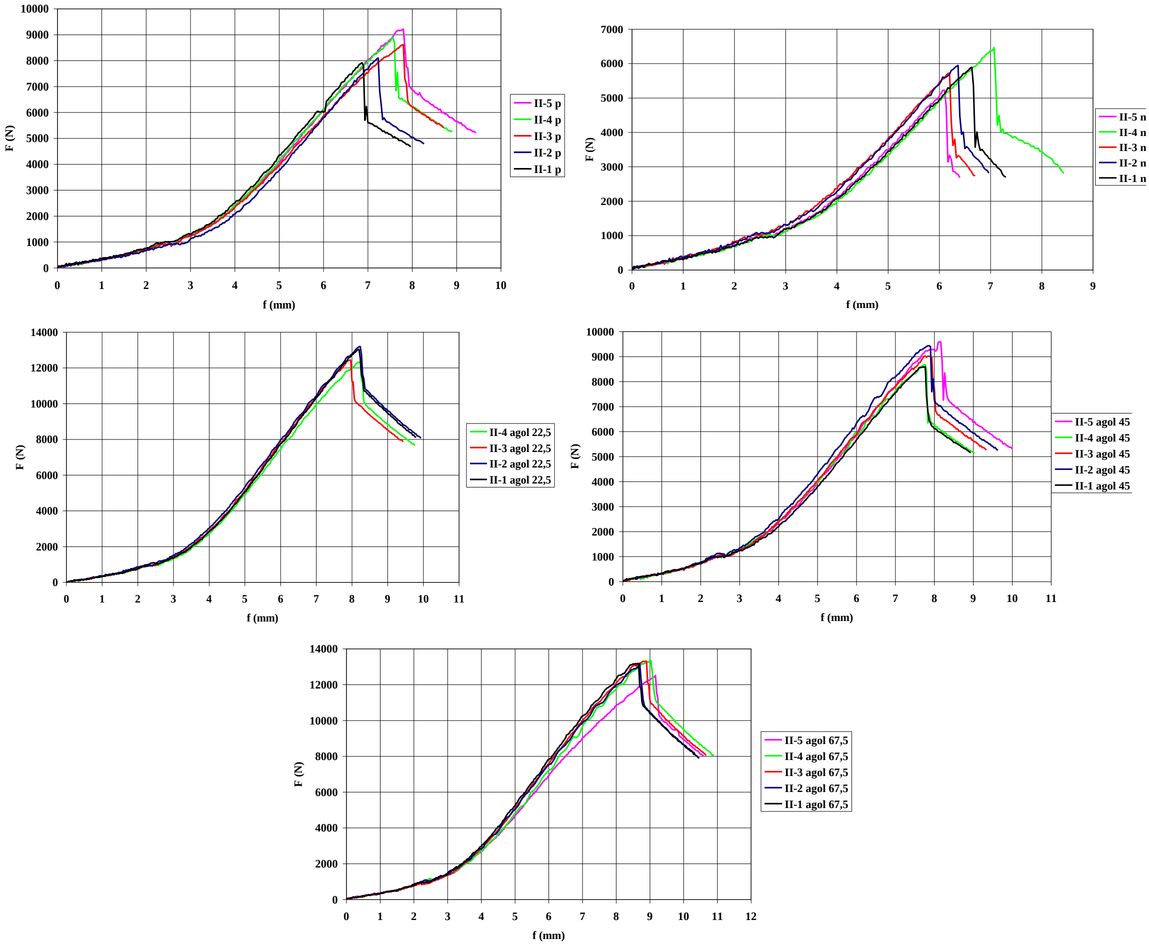


Figure 6: Force-stroke diagrams during testing of tensile strength of plywood

CONCLUSIONS

On the basis of the realized researches the following conclusions can be drawn:

- The experimental plywood model represents a stable material with a density that exceeds the requirements of the national standard for structural plywood for use in construction. The high density of plywood is basic prerequisite for high mechanical properties of the material.
- The obtained values of tensile strength in all tested directions of plywood panel exceed the defined values of this property by the national standard for wood-based panels for use in construction. The tensile strength values of experimental plywood are higher than the defined standard values for 3,5 times in direction parallel to the face grain, for 4,8 times perpendicular to the face grain and for 6 times in direction at the angles of 22,5 and 67,5º to the face grain of the panel.
- Related to the high values of tensile strength of experimental plywood it can be concluded that this plywood model is adequate for use as load-bearing panel in engineered structures in construction.
- The differences between the values of tensile strength in different directions of plywood panel are a result of the orientation of the veneers in plywood structure. The veneers with thickness of 3,2 mm in experimental plywood occupy the biggest percentage of the thickness of the plywood panel, so the value of tensile strength depends on its orientation to the direction of the tensile force. The orientation of these veneers, which is parallel to the face grain of the panel, has direct impact on achieving the highest value of the tensile strength in this direction of plywood panel.

The realized research has scientific and practical meaning. This kind of research can help in selection of materials and defining the technological parameters for production of stable plywood panels with high mechanical characteristics that can be used as load-bearing panels in construction.

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