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Article

Properties of Plywood Made from Perforated Veneers

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Abstract: The paper is focused on the bending properties of beech plywood made from veneers with perforations. The modification of the plywood was done by the targeted perforations in veneers used. The perforations were rectangular in shape 5 × 30 mm. There was a gap of 10 mm between the perforations (in each direction) and the perforations in the individual rows were shifted by 10 mm relative to each other. Two structures of lightweight plywood were investigated: sheathed (lightweight type 1) with perforated inner layers sheathed with solid veneer and perforated (lightweight type 2) with perforations in each layer. Bending properties were evaluated by three-point bend testing. The results showed decreased bending strength (MOR) as well as decreased modulus of elasticity in bending (MOE) with reduction of weight. Bending strength (MOR) was reduced by 33 to 57% and modulus of elasticity (MOE) by 13 to 43% compared to standard (non-lightweight) plywood. Bendability of lightweight plywood expressed by the minimum bending radius (R_{min}) and the coefficient of bendability (k_{oh}) point to a slight decrease in bendability by 1 to 35% compared to standard (non-lightweight) plywood. The benefit of the proposed plywood lightweight constructions is weight reduction by 16.5 to 24.4%.

Keywords: beech plywood; perforated veneer; lightweight plywood; weight reduction; bending properties

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1. Introduction

The technology of making plywood has been known and used since the time of ancient Egypt, but industrial production of plywood started to expand in the mid-19th century [1–3]. Throughout history, plywood has had various applications and it is not different at present. Plywood is used in almost all production areas, from applications in construction, to furniture production, to aviation. The development of plywood materials has not ended. At a time when much attention is focused on ecology and environmental protection, efforts to improve the construction of plywood and the technology of plywood production prevail [4–6].

The gluing process plays an important role in the production of plywood. Adhesive bonding is a key factor to produce modern, functional wood products. Adhesives entering the bonding process affect the properties of wood materials, the environment in produc-tion as well as the environment when using final products [7]. In the production of ply-wood, the adhesive can represent up to 20% of its volume [8]. Therefore, many researchers are working to improve the environmental performance of adhesives by modifying the existing adhesives and developing new environmental adhesives [5,7–10].

In recent years, research has also focused on the development of lightweight wood materials. Wood materials with a weight of less than 500 kg·m^{-3} are defined as lightweight panels, less than 350 kg·m^{-3} very lightweight panels, and less than 200 kg·m^{-3} ultra lightweight panels. Properties of lightweight wood-based materials have been researched by several authors [11–19]. One of the lightweight wood materials (plywood type), with patented production technology, won several awards in 2019 and 2020 [20]. This demonstrates the importance of research in lightweight plywood. There are several principles of weight reduction. For example, the abovementioned patented plywood is made from corrugated veneers and their subsequent cross-layering [20,21]. One way to reduce the weight of plywood is to purposefully create perforations either in the process of production plywood or in the finished plywood. The latter method is used for 2D and 3D plywood forming. The influence of different cutting patterns on deflection and load resistance was also researched [22,23].

Lightweight materials bring several benefits. In furniture design, it is possible to use greater thicknesses of the materials without increasing the weight of the products. Or, while maintaining the thickness of materials, the weight of the products can be significantly reduced, which brings benefits in handling of products and facilitates the transport of them [24]. In recent years, trends in furniture design have emphasized ensuring ergonomic standards using new environmentally friendly materials, thus promoting the optimized use of natural resources [25].

The new design of lightweight furniture is gaining more and more acceptance among end users [26]. With various methods of weight reduction of materials, the question of how to join them is also important. There are currently several means of joining which have been specially designed for joining of lightweight materials, and they can fully ensure the strength of manufactured structures [25,27,28].

Another important advantage of lightweight materials is raw material saving. This depends mainly on the proposed structure of the lightweight material (composition of file). Although, in some cases, the raw material is not saved but the desired weight reduction is obtained.

The aim of this paper is to assess the bending properties of lightweight plywood and assess the effect of the proposed plywood lightweight on the change in bending properties if compared to standard (non-lightweight) plywood. The lightweight was achieved by evenly distributed perforations in veneers in the plywood structure.

2. Materials and Methods

Rotary cut veneers made of *Fagus sylvatica* L. with the thickness of 2 mm, average density 644 $kg \cdot m^{-3}$, moisture content $6 \pm 1\%$ and dimensions of 1000×1000 mm were used. The veneers were produced and supplied by the company DYHATECH s.r.o., Král'ová Lehota, Slovakia. Formats with dimensions of 60×320 mm were cut from the veneers using CO_2 laser; half of the formats had the fiber direction oriented with longer dimension of the sheet and the other half with the shorter dimension. One half of the formats from each group was additionally modified with perforations. We determined the dimensions of the perforations based on preliminary experiments. Perforations measuring 5×30 mm were cut into the veneers using CO_2 laser, wherein the longer dimension of the perforation was always oriented in direction parallel to the wood fibers. A gap of 10 mm was left between the perforations (in each direction) and perforations in the individual rows were shifted by 10 mm to each other, as shown in Figure 1.

From the non-perforated veneers and perforated veneers, 7-layer standard (non-lighweight) plywood and lightweight plywood were pressed 14 mm thickness. The designed types of plywood were assembled according to Figure 2:

- two types of standard plywood Figure 2a,b
- four types of lightweight plywood:
    - lightweight type 1—sheathed (perforated inner layers sheathed with the solid veneer; Figure 2c,d),
    - lightweight type 2—perforated (each layer perforated; Figure 2e,f).

Each type of plywood differed in direction of wood fiber in surface veneers. The longitudinal plywood had the fiber direction in the surface veneer parallel to longer dimension of the plywood (blue veneer). The transverse plywood had the fiber direction in the surface veneer parallel to shorter dimension of the plywood (brown veneers). According to each design, 12 pieces of plywood were prepared.

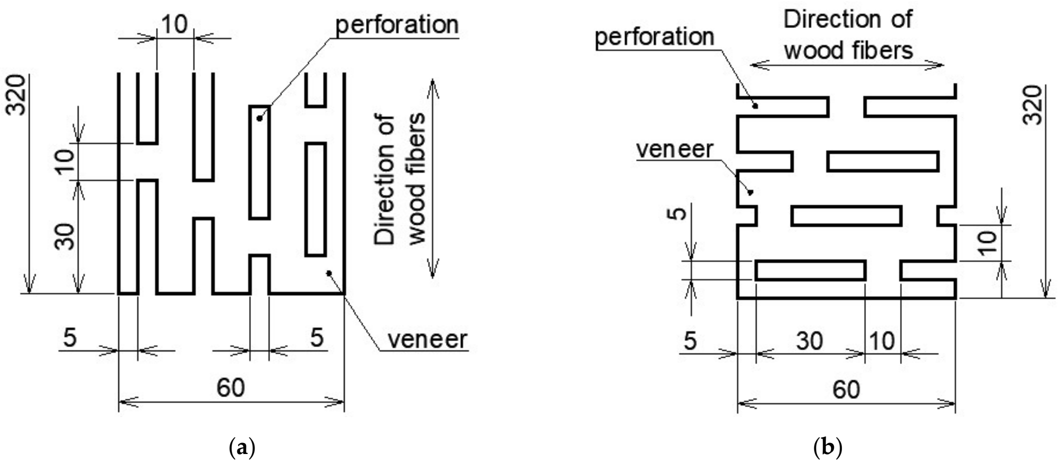


Figure 1. Arrangement of perforations in veneer with respect to direction of wood fibers. (**a**) Parallel to the longer dimension of veneer. (**b**) Parallel to the shorter dimension of veneer.

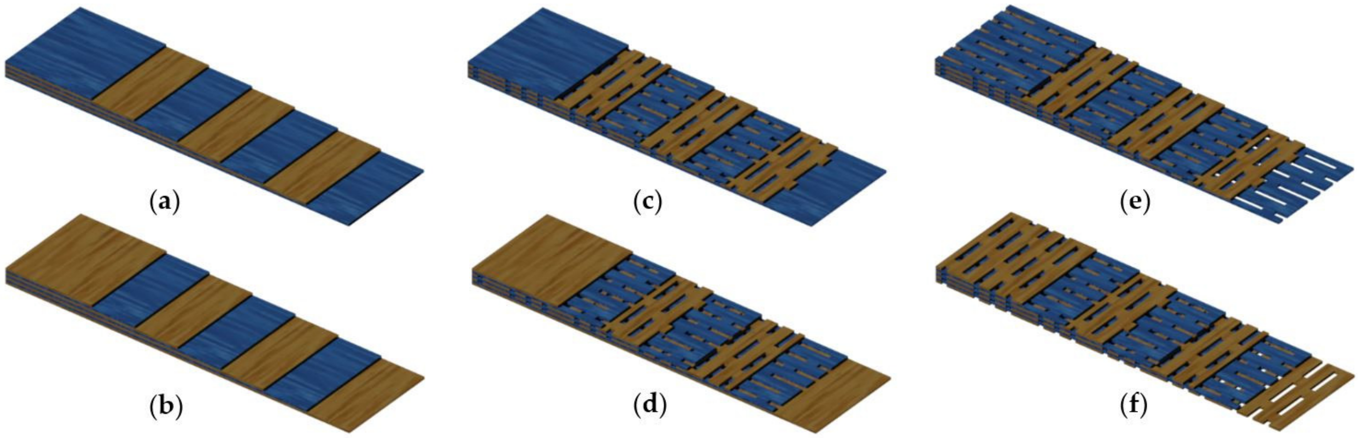


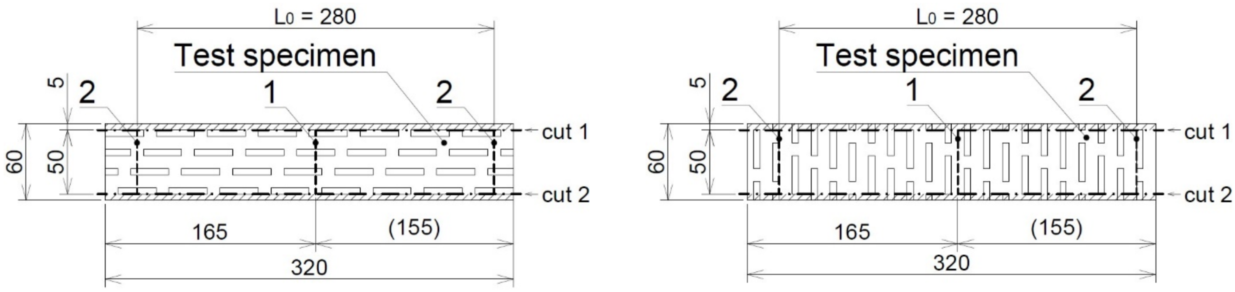
Figure 2. Plywood structures: (**a**) standard (non-lightweight) longitudinal plywood; (**b**) standard (non-lightweight) transverse plywood; (**c**) lightweight type 1 (sheathed) longitudinal plywood; (**d**) lightweight type 1 (sheathed) transverse plywood; (**e**) lightweight type 2 (perforated) longitudinal plywood; (**f**) lightweight type 2 (perforated) transverse plywood.

One-component copolymer dispersion polyvinyl acetate adhesive (PVAc) Tech-nobond (producer Agglu) with water resistance of class D3 was used to join the veneers. The spread of the adhesive was 200 g·m^{-2}. To prevent from penetrating the adhesive unnecessarily into perforations during application, the adhesive was applied using a roller. Standard (non-lightweight) plywood was the reference to determine the changes in properties of lightweight plywood.

The prepared plywood was cold pressed in a hydraulic press FONTIJNE TP 400 (Fontijne presses, Delft, The Netherlands) at a temperature of 20 ± 1 °C at a pressure of 1 MPa for 20 min. The pressing parameters were chosen according to the recommendations from adhesive manufacturer (the technical sheet). After pressing, the plywood was stacked and loaded with a weight of 30 kg, outside the press, at a relative humidity of 45% and a temperature of 20 ± 1 °C for 7 days.

Then the test specimens (surface dimensions of 50 × 320 mm) were made from all types of plywood according to Figure 3. The prepared test specimens were conditioned at a relative humidity of 45% and a temperature of 20 °C for 14 days.

After conditioning, the test specimens were tested using the bend test (Figure 4) according to the STN EN 310 standard [29] (three-point bend test). The strength and deflection were measured. The specific points of loading and supports during the bend test are shown in Figure 3.



(**a**) (**b**)

Figure 3. Test specimens made from plywood: (**a**) longitudinal plywood; (**b**) transverse plywood; where: 1—the loading point—the loading mandrel at three-point bend test, when viewed from above; 2—location of supports during three-point bend test, when viewed from above; L_0—distance of the supports at three-point bend test.

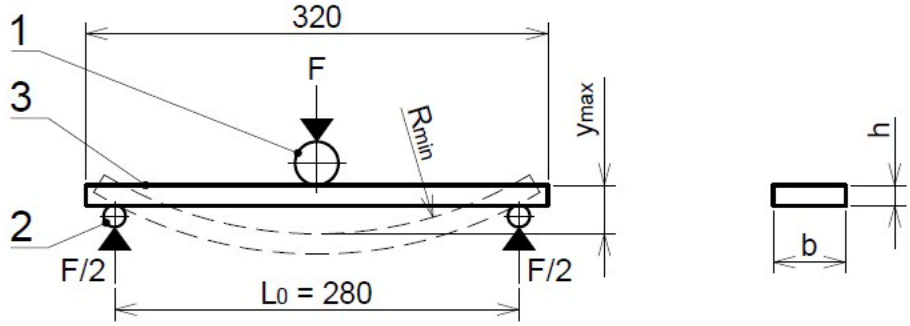
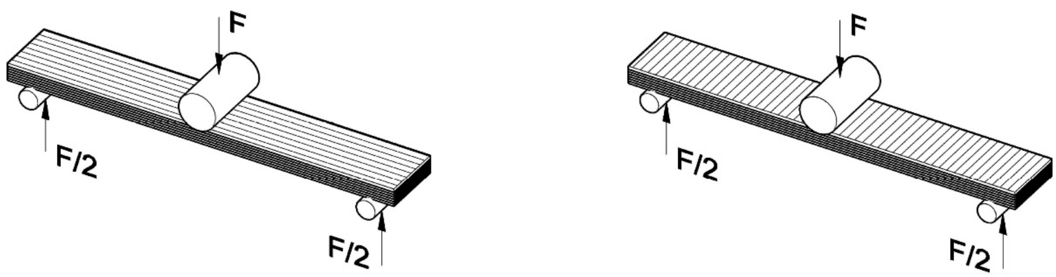


Figure 4. Schematic of three-point bend test; where: 1—loading mandrel; 2—supports; 3—test specimen; *b*—width of test specimen (mm); *h*—thickness of test specimen (mm); *F*—loading force; l_0—distance between supports (mm); R_{min}—minimum bending radius (mm); y_{max}—maximum deflection (deflection at breaking load).

During the experiment, the test specimens were loaded parallel to the fibers when the wood fibers in the surface veneer were parallel to the longitudinal axis of the test specimen (Figure 5a). The test specimens were loaded perpendicular to the fibers when the wood fibers in the surface veneer were perpendicular to the longitudinal axis of the test specimen (Figure 5b). The test specimens were loaded at a speed of 20 mm.min^{-1} using the LabTest 4.050 testing machine (LaborTech, Opava, Czech Republic).



(**a**) (**b**)

Figure 5. Loading of the test specimens with respect to the longitudinal axis of the test specimens and direction of wood fibers. (**a**) Parallel to the fibers—longitudinal plywood. (**b**) Perpendicular to the fibers—transverse plywood.

According to the STN EN 310 [29] standard, the bending strength (MOR—Equation (1)) and the modulus of elasticity in bending (MOE—Equation (2)) were calculated from the measured parameters. Other calculated and monitored characteristics were: the minimum bending radius (R_{min}—Equation (3)) presented by works [30–32], and the coefficient of bendability (k_{oh}—Equation (4))

$$\text{MOR} = \frac{3 \cdot F_{max} \cdot l_0}{2 \cdot b \cdot h^2} \quad (1)$$

$$\text{MOE} = \frac{l_0^3 \cdot (F_{40} - F_{10})}{4 \cdot b \cdot h^3 \cdot (y_{40} - y_{10})} \quad (2)$$

$$R_{min} = \frac{l_0^2}{8 \cdot y_{max}} + \frac{y_{max}}{2} \quad (3)$$

$$k_{oh} = \frac{h}{R_{min}} \quad (4)$$

where MOR is the bending strength (MPa), F_{max} is breaking force (N), l_0 is distance between supports = 20 · h (mm), b is test specimen width (mm), h is test specimen thickness (mm), MOE is the modulus of elasticity in bending (MPa), F_{40} is 40% from F_{max} (N), F_{10} is 10% from F_{max} (N), y_{40} is deflection at force of F_{40} (mm), y_{10} is deflection at force of F_{10} (mm), R_{min} is the minimum bending radius (mm), y_{max} is maximum deflection (deflection at breaking load) (mm), k_{oh} is the coefficient of bendability (−).

In addition to the bending characteristics, the percentage of change in weight of the lightweight plywood was also evaluated.

The calculated characteristics were analyzed by multifactor analysis of variance and Duncan tests using the program STATISTICA 12. The results were evaluated for the 95% confidence interval (significance level $p < 0.05$) and expressed in tables and graphs. The evaluated factors were: the structure of plywood (standard non-lightweight; sheathed lightweight type 1; perforated lightweight type 2), and the method of loading with respect to the fiber direction (parallel, perpendicular).

3. Results and Discussion

On the produced plywood (test specimens), the changes in bending strength, modulus of elasticity in bending, bendability, and weight reduction of the material were evaluated.

3.1. Bending Strength (MOR)

One-dimensional significance tests for bending strength (MOR), resulting from multifactor analysis of variance (Table 1), confirmed that the observed factors—as well as their interaction—significantly influenced the bending strength. The Fisher's F-test confirmed that bending strength was affected by the direction of loading to a greater extent than by the plywood structure.

In Figure 6, it is clearly seen how the structure of plywood affected the bending strength. The highest MOR (88.65 MPa) found is very close to MOR for beech plywood (86.6 MPa and 98.7 ± 11.5 MPa) found by Reinprecht et al. [33] and Ružiak et al. [34].

When comparing the same plywood structure at different directions of loading, a decrease in bending strength for the plywood loaded perpendicular to the fibers was observed. For standard plywood, the decrease was by 37.82%. There was a decrease of 45.26% for lightweight sheathed plywood and 44.49% for lightweight perforated plywood. For standard beech plywood and loading in different directions, Bal and Bektas [35] recorded a MOR difference of 50.9–57.3%, depending on the type of adhesive used.

The differences in MOR, depending on the direction of loading, can be explained by the fact that if the test specimen is loaded perpendicular to the fibers, there is larger number of veneers with fibers oriented parallel to the shorter dimension of the test specimen. According to the findings of Bal and Bektas [35], we assume that the applied adhesive also affected the changes. From the view point of strength, the proposed structures of lightweight plywood did not contribute to elimination (equabling) of differences caused by loading direction. Due to the lightweight plywood, an increase in the difference of about 7% was noticed.

Table 1. Statistical evaluation of the effect of the observed factors and their interaction on the bending strength (one-dimensional significance tests for MOR).

Source of Variability	Sum of Squares	Degrees of Freedom	Variance	Fisher's F-Test	Significance Level (*p*)
Overall Average	183,338.73	1	183,338.73	7141.515	0.000 *
Direction of Loading	12,682.67	1	12,682.67	494.023	0.000 *
Plywood Structure	18,514.06	2	9257.03	360.585	0.000 *
Direction of Loading × Plywood Structure	630.46	2	315.23	12.279	0.000 *
Random Factors	1694.37	66	25.67		

Note: * significant at $p < 0.05$.

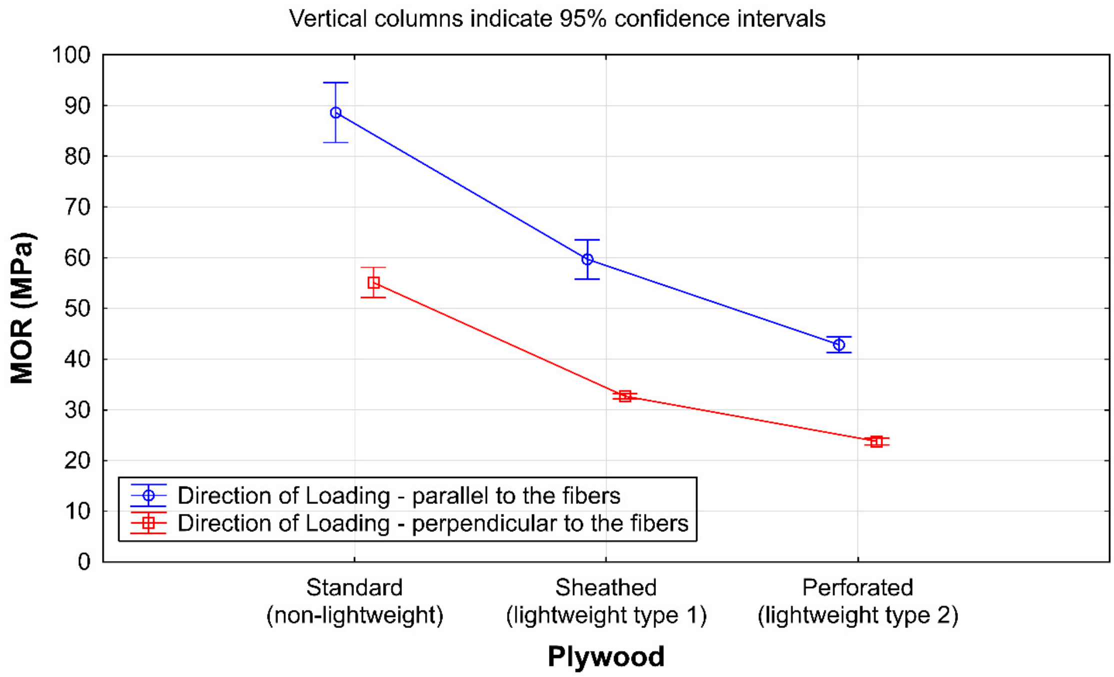


Figure 6. Influence of plywood structure on the bending strength in the directions of loading—parallel and perpendicular to the fibers.

Regardless of the direction of load, a decrease in bending strength for the lightweight plywood was noticed.

By perforations in the construction of lightweight plywood, the size of the bonded surface was significantly reduced, which contributed to the reduction in MOR. The bonded surface between the individual layers of veneer is only in places where the perforations do not overlap each other. Compared to standard plywood, the bonded surface decreased by an average of 41% for sheathed plywood (lightweight type 1) and by 47.8% for perforated plywood (lightweight type 2). The difference is not large, but the higher bending strength (MOR) of the sheathed plywood (lightweight type 1) was due to the solid veneers in the surface layers, which affected the size of bonded surface. We can state that the smaller the bonded surface is, the lower the MOR is.

Figure 6 shows that bending strength decreases with smaller bonded surface and lower weight of plywood. If compared to standard plywood, the most significant decrease in bending strength was recorded for perforated plywood (lightweight type 2). If loaded parallel to the fibers, the decrease in bending strength was 51.67%, and if loaded perpendicular to the fibers the decrease was 56.86%. Lightweight plywood sheathed with solid veneer (lightweight type 1) showed a smaller decrease in bending strength. Specifically, if loaded parallel to the fibers by 32.66% and if loaded perpendicular to the fibers by 40.71% (when compared to standard plywood).

From Figure 6, it can be seen that the 95% confidence intervals of the detected bending strength (MOR) for the proposed structures and loading directions are not overlapping at all. This fact signals the statistical significance of the observed decrease in bending strength. The significance of the detected changes was also confirmed by the Duncan test (Table 2), where all levels of significance were lower than 0.05.

Table 2. Duncan test: Comparison of the effects of individual factors on bending strength (MOR).

Number	Direction of Loading	Plywood Structure	(1) 88.65 **	(2) 59.71 **	(3) 42.84 **	(4) 55.12 **	(5) 32.67 **	(6) 23.78 **
1.	Parallel	Standard						
2.	Parallel	Sheathed	0.000 *					
3.	Parallel	Perforated	0.000 *	0.000 *				
4.	Perpendicular	Standard	0.000 *	0.030 *	0.000 *			
5.	Perpendicular	Sheathed	0.000 *	0.000 *	0.000 *	0.000 *		
6.	Perpendicular	Perforated	0.000 *	0.000 *	0.000 *	0.000 *	0.000 *	

Notes: * significant at $p < 0.05$; ** average MOR (MPa).

3.2. *Modulus of Elasticity in Bending (MOE)*

The analysis of the calculated modulus of elasticity in bending (MOE) showed that all observed factors and their interactions affect the MOE. The found-out levels of significance are shown in Table 3. As in the case of MOR, according to the F-test, the direction of loading and then the structure of plywood had the greatest influence on the change in MOE.

Table 3. Statistical evaluation of the effect of the observed factors and their interaction on modulus of elasticity in bending (one-dimensional significance tests for MOE).

Source of Variability	Sum of Squares	Degrees of Freedom	Variance	Fisher's F-Test	Significance Level (*p*)
Overall Average	1.66×10^9	1	1.66×10^9	17,928.161	0.000 *
Direction of Loading	2.72×10^8	1	2.72×10^8	2930.911	0.000 *
Plywood Structure	6.82×10^7	2	3.41×10^7	367.946	0.000 *
Direction of Loading × Plywood Structure	1.12×10^7	2	5.60×10^6	60.415	0.000 *
Random Factors	6.12×10^6	66	9.27×10^4		

Note: * significant at $p < 0.05$.

By comparing the modulus of elasticity in bending (MOE), we found the decrease with reduction of weight (Figure 7). If compared to standard (non-lightweight) plywood, the MOE in lightweight plywood constructions decreased by 40% approximately. The result was expected, as the air gaps in the structure of lightweight plywood reduce the proportion of wood and glue in the volume of test specimens, which logically must also reduce the MOE. The lower modulus of elasticity of lightweight plywood may not be a disadvantage, but quite the opposite. Materials with a lower modulus of elasticity are less rigid and more elastic, which can be used to a greater extent—for example, in the technology of forming furniture parts.

In the case of sheathed plywood (lightweight type 1) loaded parallel to the fibers, we recorded low 13% decrease in the modulus of elasticity. The longitudinal veneers in the surface layers of the plywood, which provided a higher rigidity, are the cause for the lower decrease in MOE.

The direction of loading during the bend testing was reflected in the modulus of elasticity in bending (MOE) similar to the situation for MOR. For the same plywood construction, the modulus of elasticity in loading perpendicular to the fibers was, on average, 51 to 66% lower compared to loading parallel to the fibers.

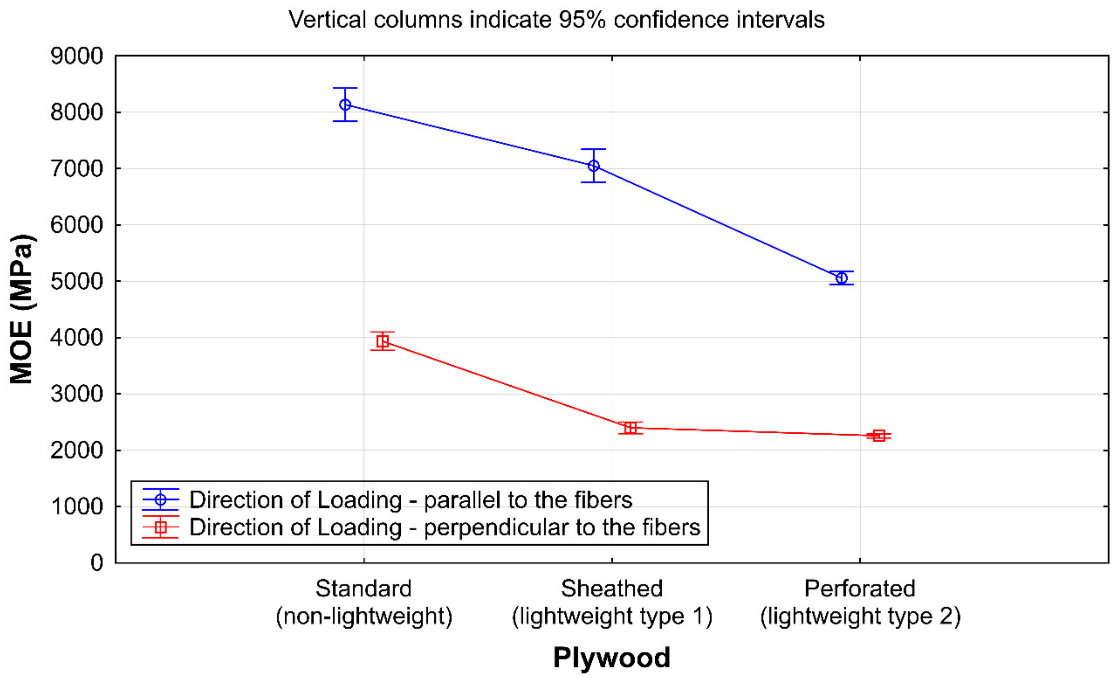


Figure 7. Influence of plywood structure on the modulus of elasticity in bending; loading parallel and perpendicular to the fibers.

The difference in MOE between the loading directions is not surprising. A similar decrease in MOE perpendicular to the fibers was also recorded by Merhar [36] and Štefko and Joščák [37] when testing a standard plywood. Bal and Bektas [35] recorded a decrease in MOE of 67.5 to 69.2%, but for different types of adhesives. Our results are confirming the conclusions of Buchelt and Wagenführ [38] on the influence of adhesive on mechanical properties of materials based on thin veneers; they consider the adhesive to be one of the causes of the reported differences.

The Duncan test (Table 4) shows a detailed comparison of the significance of changes in MOE induced by the plywood structure and the direction of loading. In one case (loading perpendicular to the fibers), no significant difference in the change of MOE between sheathed and perforated plywood was confirmed. This was also indicated in the graph in Figure 7. It follows that both the lightweight plywood structures behave as equally elastic, although perforated plywood is more lightweight (outer veneers also perforated).

Table 4. Duncan test: Comparison of the effects of individual factors on the modulus of elasticity (MOE).

Number	Direction of Loading	Plywood Structure	(1) 8137.1 **	(2) 7050.7 **	(3) 5055.7 **	(4) 3934.5 **	(5) 2397.1 **	(6) 2255.0 **
1.	Parallel	Standard						
2.	Parallel	Sheathed	0.000 *					
3.	Parallel	Perforated	0.000 *	0.000 *				
4.	Perpendicular	Standard	0.000 *	0.000 *	0.000 *			
5.	Perpendicular	Sheathed	0.000 *	0.000 *	0.000 *	0.000 *		
6.	Perpendicular	Perforated	0.000 *	0.000 *	0.000 *	0.000 *	0.257	

Note: * significant at $p < 0.05$, ** average MOE (MPa).

3.3. Degree of Weight Reduction

Through the proposed dimensions of the perforations and their arrangement in the individual veneers intended for construction of the lightweight plywood, a certain weight reduction was achieved.

In the case of the plywood having a lightweight core sheathed with solid veneer (lightweight type 1), an average weight reduction of 16.52% was achieved. In the case of the perforated plywood (lightweight type 2), a significantly higher percentage of weight reduction was achieved (24.41%). A similar percentage of weight reduction in a different design of the structure of lightweight plywood materials was achieved in the research by Vilhanová and Dudas [39], Vilhanová and Gáborík [40]. Even in the material AEROWOOD®, air makes up almost 30% of the panel's volume [21].

3.4. Bendability of Plywood

For the purposes of suitability of the designed lightweight plywood for production of bended parts, it is necessary to evaluate the technological property—bendability. Bendability is characterized by the coefficient of bendability (k_{oh}) or it can also be expressed by the minimum bending radius (R_{min}).

The significance of the influence of the observed factors and their interaction on the minimum bending radius (R_{min}) can be evaluated based on levels of significance (Table 5). All factors and their interaction proved to be significant, with R_{min} influenced most by the direction of loading.

Table 5. Statistical evaluation of the effect of observed factors and their interaction onto the minimum bending radius (one-dimensional significance tests for R_{min}).

Source of Variability	Sum of Squares	Degrees of Freedom	Variance	Fisher's F-Test	Significance Level (p)
Overall Average	29,136,283	1	29,136,283	4574.543	0.000 *
Direction of Loading	1,239,161	1	1,239,161	194.554	0.000 *
Plywood Structure	269,618	2	134,809	21.166	0.000 *
Direction of Loading × Plywood Structure	193,041	2	96,521	15.154	0.000 *
Random Factors	420,369	66	6369		

Note: * significant at $p < 0.05$.

Figure 8 shows the changes in the minimum bending radius (R_{min}) found for the plywood structures under loading in directions parallel and perpendicular to the fibers. The findings confirm higher R_{min} in all tested plywood structures when the test specimens were loaded parallel to the fibers. For standard (non-lightweight) plywood, a difference in R_{min} of 188.71 mm was recorded (an increase by 41.3%). For sheathed plywood (lightweight type 1), the difference in R_{min} was 408.83 mm (an increase by 88.7%); and for perforated plywood (lightweight type 2), the difference in R_{min} was 190.35 mm (an increase by 31.9%).

Comparing the values of R_{min} depending on the structure of plywood, no significant difference between standard and sheathed plywood was noticed if the plywood was loaded perpendicular to the fibers. This is confirmed by the Duncan test (Table 6), where the significance level was 0.897. From the view point of bendability of lightweight plywood, this is an important finding. The result confirms that the same minimum bending radius as for standard plywood can be achieved by a suitable design of lightweight plywood, which can be used in the production of bended furniture.

Comparing the values of minimum bending radius for standard (non-lightweight) and sheathed plywood (lightweight type 1) if loaded parallel to the fibers, a completely opposite effect was observed—a significant increase in the bending radius for the sheathed plywood (increase of 224.36 mm = 34.8%). This represents an undesirable effect in terms of bendability of the material modified in this way. When loaded parallel to the fibers, perforated plywood showed slightly better results; where R_{min} increased by 141.57 mm (by 21.9%) if compared to the standard plywood. An undesirable increase in R_{min} was also recorded for perforated plywood when loaded perpendicular to the fibers; R_{min} increased by 139.93 mm (by 30.6%).

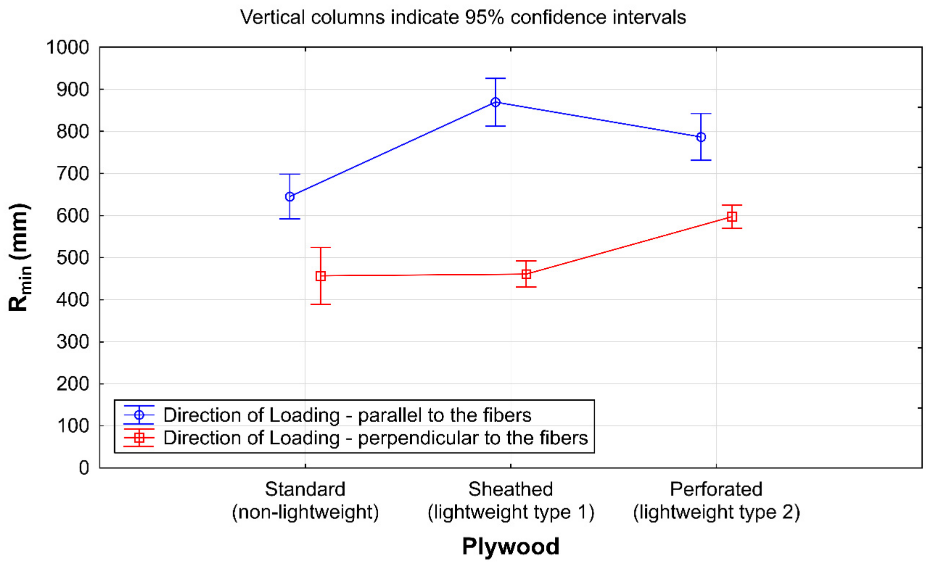


Figure 8. Influence of plywood structure on the minimum bending radius: loading parallel and perpendicular to the wood fibers in the surface veneer.

Table 6. Duncan test: comparison of the effects of individual factors on the minimum bending radius (R_{min}).

Number	Direction of Loading	Plywood Structure	(1) 645.35 **	(2) 869.71 **	(3) 786.92 **	(4) 456.64 **	(5) 460.88 **	(6) 597.33 **
1.	Parallel	Standard						
2.	Parallel	Sheathed	0.000 *					
3.	Parallel	Perforated	0.000 *	0.014 *				
4.	Perpendicular	Standard	0.000 *	0.000 *	0.000 *			
5.	Perpendicular	Sheathed	0.000 *	0.000 *	0.000 *	0.897		
6.	Perpendicular	Perforated	0.145	0.000 *	0.000 *	0.000 *	0.000 *	

Notes: * significant at $p < 0.05$; ** average R_{min} (mm).

To compare the bendability for the proposed plywood structures mutually (without the influences of thickness and determined R_{min}), the coefficients of bendability (k_{oh}) were calculated according to the Formula (4) (Table 7). Based on k_{oh}, it can be clearly determined which of the proposed plywood structures is bendable best. The closer to number one the k_{oh} is, the more bendable the material is (at the given thickness, it is possible to achieve smaller R_{min}).

Table 7. Calculated coefficients of bendability (k_{oh}) depending on the plywood structure and the direction of loading during the three-point bending test.

Direction of Loading	Plywood Structure	k_{oh} (−)
Parallel	Standard	0.022
Parallel	Sheathed	0.016
Parallel	Perforated	0.018
Perpendicular	Standard	0.033
Perpendicular	Sheathed	0.030
Perpendicular	Perforated	0.023

4. Conclusions

Based on the results, we can draw the following conclusions:

Compared to standard plywood, we recorded a decrease in bending strength for lightweight plywood. The more weight reduction, the lower the bending strength. For the sheathed plywood (lightweight type 1), the bending strength decreased by 32.66 to

40.71%. For perforated plywood (lightweight type 2), the bending strength decreased by 51.67 to 56.86%.

If changing the direction of loading from parallel to the fibers to perpendicular to the fibers, the bending strength of standard plywood decreased by 37.82%, sheathed plywood by 45.26%, and perforated plywood by 44.49%.

The modulus of elasticity in bending decreased with weight reduction of plywood by almost 40% in almost all cases. Taking into account direction of loading, the MOE parallel to the fibers was by 51 to 66% higher than MOE perpendicular to the fibers.

The results confirm that similar bendability as with standard plywood can be achieved by a suitable construction of lightweight plywood. Compared to standard plywood, the bendability of lightweight plywood indicates a slight decrease in bendability by 1 to 35%. From the evaluated materials, sheathed plywood is more suitable for forming purposes.

In the designed structures of lightweight plywood, we achieved a weight reduction by 16.52% for sheathed plywood and 24.41% for perforated plywood. With the correct design of the structure of wood-based plywood materials, it is possible to reduce their weight to a relatively significant extent, which in turn can expand the application possibilities of these materials.

Lightweight plywood can be used in the construction of upholstered furniture as well as in other types of furniture with the requirement for greater thickness of parts; it will ensure a reduction in weight of the furniture structure. The use is also possible in the pro-duction of flat shaped parts of furniture. Related to this is the need for research aimed at joining of lightweight plywood. Another interesting area of research of perforated plywood may be its acoustic properties.

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