Assessing the bending strength and modulus of elasticity in bending of exterior foiled plywoods in relation to their construction

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ABSTRACT: The paper summarizes results of an institutional research aimed at assessing the bending strength and modulus of elasticity in bending of exterior foiled combined and all-beech plywoods in relation to their construction. A relationship was studied of the plywood construction and selected physical and mechanical properties. In studied sheets, moisture, density, bending strength and modulus of elasticity were analysed along and across the grain of the upper veneer. All measurements were carried out in water-resistant plywoods with surface treatment with a phenolformaldehyde foil 8, 10, 12 and 15 mm thick in combined plywoods and 10, 12, 15 and 18 mm thick in all-beech plywoods. The construction of plywoods significantly influences their quality that is determined particularly by the bending strength and modulus of elasticity. Using regression analysis relationships were demonstrated particularly that with the increasing moisture content of plywoods the bending strength decreased and with the increasing density the bending strength and modulus of elasticity increased. The same trend was also proved in connection with the increasing number of veneers of plywood sheets. Using correlation analysis, combinations of interrelationships of the given properties were statistically tested.

Keywords: plywood; density; surface density; moisture; thickness; bending strength; modulus of elasticity in bending; veneer; statistical analysis

Plywood sheets are defined as sheets with mutually glued plies, the direction of fibres of neighbouring plies being perpendicular to each other. In general, outside and inside plies on both sides are symmetrical with respect to the core (or central ply).

The manufacture of plywood sheets belongs to the youngest branches of the wood-processing industry. Plywood sheets have occupied one of the leading places on the market of large-area materials. They are used in many sectors of human activities, e.g. in engineering, textile industry, furniture manufacture, transport, industrial and building production, etc.

Plywood materials, together with agglomerated materials are ranked among large-area materials. They are manufactured by hot-pressing the sets of veneers spread with a synthetic adhesive under interaction of pressure.

As against agglomerated materials, i.e. particleboards and fibreboards, they show certain advantages. They are substantially lighter (showing lower density) and demonstrate higher values of particular mechanical and physical properties. Their main advantage is that they maintain an appearance of natural wood. Plywood sheets can also be manufactured as formed moulded articles. In general, their coating (surface finish) is simple. According to the purpose of use, plywood sheets can be manufactured as exterior (water-resistant) plywoods by adding special types of synthetic adhesives or using special foils.

Plywood sheets show, however, the greatest use in furniture industry (non-water-resistant plywoods). In building industry, however, exterior water-resistant plywood sheets are used. Building industry uses plywood sheets also for the construction and manufacture of floors, plywood lining, structural walls, laminated constructions, etc. As for transport, plywood sheets are used in the manufacture of railway cars, buses, trams, lorries, ships, etc.

Plywood sheets are categorised according to the construction to plywoods (joinery, building, packaging, aircraft, laminated wood), core boards (laminboards, blockboards, battenboards, veneered boards), sandwich boards (honey-comb panels) and also according to the form (flat and shaped).

Another categorisation of plywood sheets can be made according to main qualitative parameters, i.e. according to service life (for use in outdoor conditions and in the interior dry environment), mechanical properties, surface appearance, surface treatment (sanded, non-sanded, surface treated, coated).

The plywood sheet quality is assessed according to many criteria and characteristics. Generally, it is possible to state that plywood sheets are classified according to particular standards. They have to meet requirements for size accuracy (sizes and dimension stock), gluing quality, external qualitative parameters, physical and mechanical properties, special requirements of customers (decreased release of formaldehyde, increased fire resistance, mould, fungi and insect resistance).

Bending strength and modulus of elasticity (MOE) in bending of plywood materials are affected by a number of factors, viz. tree species, tree quality, wood moisture, wood density, wood structure, temperature, number of plies, adhesive, and permanent load.

Effects of wood moisture

The moisture content of veneers used for the production of plywood sheets ranges between 4 and 10%. Strength and elastic properties of wood and wood-based materials are dependent on the moisture content up to the fibre-saturation point. Above the point, the properties do not change any more. Within the moisture range of 8 to 18%, changes in properties of wood and plywood sheets are most intensive being linear. With the moisture change by 1% (at a range of 5–30%) the bending strength is changed by 4% and MOE by 1% (Šteller 1978).

Effects of density

With the increasing density, MOE in bending and bending strength increase. The relation is expressed linearly. The relationship between density and mechanical properties of wood is more complicated because wood strength is dependent not only on its density but also on its anatomical structure. Effects of density are most shown in dry wood being inexpressive at the moisture content above the hygroscopicity point (Šteller 1967).

Effects of temperature

With the increasing temperature MOE in bending and bending strength decrease. Effects of a temperature on mechanical properties change with the moisture content. Interactions of temperature and wood moisture are markedly manifested at 60–90°C. With the increasing temperature and moisture content wood strength markedly decreases. Simultaneous effects of both the factors decrease the wood strength more than separate effects of each of the factors (Matovič 1993).

Effects of permanent load

In practice, except short-term load timber structures are stressed also by permanent load. Under long-term load, wood deformation occurs (Koželouh 1998). With a longer period of load the values characterising wood strength decrease. Therefore, under conditions of permanent load the results from short-term static loads cannot be used. Long-term behaviour of plywoods is based on wood quality, course of load, wood moisture and wood temperature. Therefore, it is necessary to take into account a reduction of the bending MOE value for permanent load by a certain value, viz.:

– for long-term load operating more than 1 year: 0.7–0.4
– for medium-term load operating less than 1 year: 0.8–0.6
– for short-term load operating less than 1 week: 1.0–0.7.

Effects of the number of plies

In bending load, a decisive role is played by the geometrical arrangement of particular plies. Properties of particular plies and their proportion in the total thickness of a sheet are a cardinal parameter. In elements subject to bending load, it is possible to carry out the extreme reduction of a central ply (e.g. using the honeycomb structure or foams) and thus to obtain relatively light combined boards with the high modulus of elasticity and bending strength. The reduction of central plies can, however, cause problems in the application of the boards, e.g. in mounting fittings (Baldwin 1973).

Effects of structure

The fibre direction angle between particular plies, type of adhesive and the proportion of a gluing mixture including the impregnation of plies with an adhesive to increase densification and also wood density (the degree of densification as compared with solid wood – Požgaj et al. 1993) show dominant effects on the properties of wood and plywood sheets (MOE in bending, bending strength). The following factors exert considerable effects: tree species, wood quality, veneer thickness and the proportion of an extender in the gluing mixture. The type of adhesive determines resistance to weather effects. Taking into account particular factors mentioned above the properties of solid wood can be even exceeded. As compared with solid wood marked homogenisation can be achieved because defective spots (knots, splits, etc.) are evenly distributed. A possibility to adapt the anisotropy of plywood sheets to a certain constructional function by the choice of the thickness profile appears to be a great advantage of plywood sheets that cannot be achieved by competitive semifinished products at all or only by a very difficult adaptation of production technology. The producer of plywood sheets is, however, limited by regulations on the admissible thickness of particular veneers. Relationships between the sheet construction and elastic and strength properties make it possible to calculate elastomechanical properties (when the sheet construction is known) or under requirements for certain elastomechanical properties to find out the sheet construction that can fulfil the requirements.

Present trends in veneer and plywood production are characterised by the fact that production has been transferred into regions with cheap working sources and inexpensive labour. Asia has accounted for the largest proportion since 1991. In 2000, it was already 48% of the world production of plywoods. The second largest producer of plywoods is North America with 34% market share. Europe occupies the third position with only 10% of the world production.

In many regions, plywood production is oriented to various special products the purpose of which is to substitute solid wood in other technologies or other kinds of materials, for example metals and plastics. Maximum use of decorative properties of natural wood is also of great importance.

Another effect influencing the plywood production is the expansion of production of other types of large-area materials, mainly particleboards and fibreboards. These cheaper materials lead to a decreased use of plywoods in standard technologies, e.g. in the manufacture of furniture and wooden constructions, which naturally results in the stagnation of plywood sheet production.

Fig. 1 depicts the situation of the production, exports and imports of plywoods in the CR. The figure indicates the stagnation of plywood production due to the high volume of imports of cheaper plywood sheets from Asia, Brazil, etc. The increasing export of plywoods from the Czech Republic accounted, however, for only 2.3% from the total volume of exports of wood products in 2000. Sawn timber with its volume of 1,701,000 m^3 shows the largest proportion in exports from the CR.

The aim of the paper was to assess the bending strength and modulus of elasticity of exterior foiled plywoods in relation to their construction.

Mechanical loading means the process when interactions occur between mechanical forces and other loading factors in wood. Temporary or permanent changes in the body form are a result of the process.

According to physical nature, loading of wood or wood-based materials is divided into mechanical, moisture, thermal and other types of loading.

During the action of an external force on a body a stress (σ) occurs in the body. The stress is defined as the size of an internal force related to the unit area. If forces act perpendicularly to the body surface, it is normal stress. It is calculated according to the following relation:

$$\sigma = \frac{F}{S}$$

where: F – the force uniformly acting on the body surface (N),
S – the body surface (mm^2).

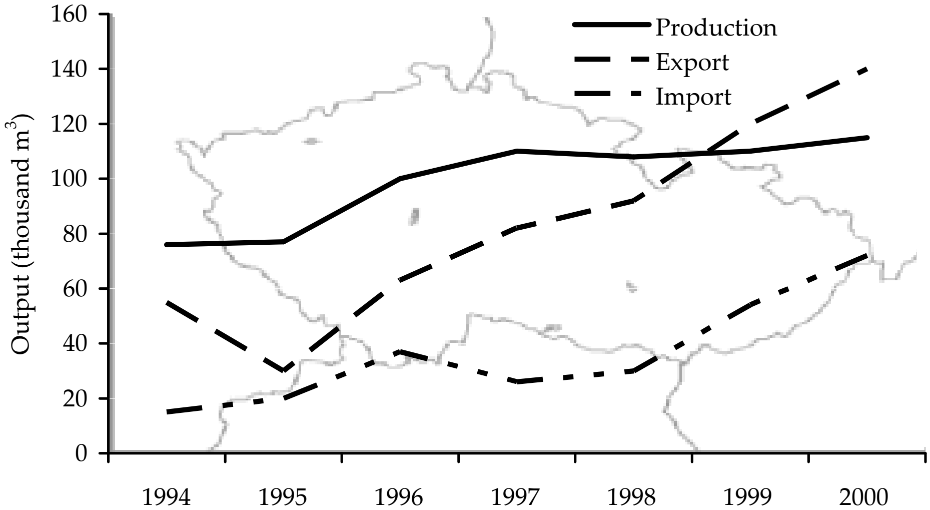

Fig. 1. Production, exports and imports of plywood sheets in the Czech Republic (according to FAO data)

If forces act parallelly to the body surface, they cause so-called shear stress (τ). It is calculated according to the following relation:

$$\tau = \frac{F_\tau}{S}$$

where: F – the force uniformly acting on the body surface (N),
S – the body surface (mm^2).

Normal and shear stress is expressed in N/mm^2.

Because of the effect of external forces, changes in the body size, volume or shift in dimensions occur and thus also the partial change in the body form. These changes are called deformations.

Wood or more accurately the basis of its cell walls represents in principle a complex of natural polymers with long chain molecules. The structure of polymers determines the nature of their behaviour under loading. If external forces act on the polymers, the following three types of deformations can occur:
– immediate elastic deformation (ε_p) – caused by reversible changes in average distances between chain molecules of polymers (it occurs immediately during the action of the force and after its relaxation it promptly disappears);
– elastic deformation developing with time (ε_t) – sometimes called elastic deformation connected with the reversible rearrangement of particles of chain molecules (it increases gradually with time and disappears after some time after relaxation);
– plastic (irreversible) deformation (ε_{pl}) – caused by intermixing the chain molecules. It remains after the acting force was relaxed (it is also called residual deformation, permanent deformation).

In wood, deformations caused by changes in the moisture content occur very often. Wood obtains various dimensions thereby being deformed. Swelling represents elastic deformations. As soon as wood changes its dimensions and shape, internal forces have to originate in the wood causing stress (moisture stress). After the removal of water from the wood structure the wood obtains its original dimensions and deformations disappear.

Relationships between stress and deformation provide very useful information for the development of production of construction materials of wood. These relationships are of great importance mainly in determining parameters for plywood pressing, laminated densified wood, particleboards, etc.

Characteristics of failures in bending stress are various. They are primarily dependent on the geometry of shape, wood structure and effects of external forces. Several basic characteristics of failures are distinguished (Figs. 2–5).

Fig. 2. Failure in the central ply caused by the effect of shear stress

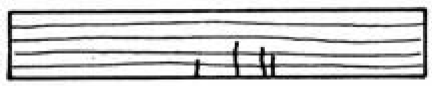

Fig. 3. Failure caused by the fibre rupture in the tensile zone

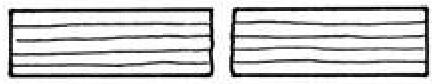

Fig. 4. Failure – a blunt fracture along the height of the body

Fig. 5. Fibrous failure along the height of the body

MATERIAL AND METHODS

Tests were carried out on foiled exterior plywood sheets of two types of construction with slip-resistant (skidproof) treatment.

The construction of combined plywood sheets is given in Table 1 and that of all-beech plywood sheets in Table 2.

In both types of plywood sheet construction, producers give the surface density of surface foils 167 g/m^2, gluing class 3 according to ČSN EN 314-2 (49 0173) standard, i.e. complying with AW 100 test and formaldehyde emission class A according to ČSN EN 1084 (49 2407) standard.

According to EN 326-1 and EN 325 standards, plans of plywood cutting were prepared. An example of the plan for plywoods 15 mm thick is depicted in Fig. 6. The number of samples used for the tests is given in Table 3.

Particular physical and mechanical properties of plywood sheets were determined according to the following standards:
– ČSN EN 310 Determination of modulus of elasticity in bending and bending strength
– ČSN EN 322 Boards of wood – Determination of moisture
– ČSN EN 323 Boards of wood – Determination of density

Table 1. Construction of exterior plywoods – combined plywoods

Plywood thickness	Number of plies	Construction
8	5	1.5 – 2.6 – 1.5 – 2.6 – 1.5
10	7	1.5 – 1.8 – 1.5 – 1.8 – 1.5 – 1.8 – 1.5
12	7	1.5 – 2.6 – 1.5 – 2.6 – 1.5 – 2.6 – 1.5
15	7	1.5 – 3.5 – 1.5 – 3.5 – 1.5 – 3.5 – 1.5
18	9	1.5 – 3.5 – 1.5 – 3.5 – 1.5 – 3.5 – 1.5 – 3.5 – 1.5
Veneer thickness 1.5 mm – beech		other veneer thickness – coniferous species

Table 2. Construction of exterior plywoods – all-beech plywoods

Plywood thickness	Number of plies	Veneer thickness of all plies (mm)
10	7	1.5
12	9	1.5
15	11	1.5
18	13	1.5

Table 3. Number of samples for particular tests from one plywood sheet

Sample designation	Type of the test	Number of samples
A	Moisture	combined 4/all-beech 8
B	Density	16
C	Density profile	6
D	Modulus of elasticity and bending strength	8
E	Wettability	12
F	Dimension change	4

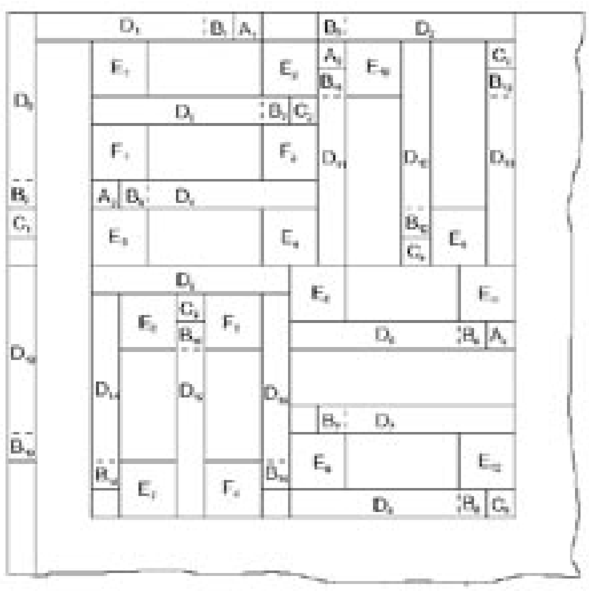

Fig. 6. Plan of cutting for a plywood 15 mm thick

– ČSN EN 325 Determination of dimensions of sample pieces
– ČSN-EN 326 -1 Boards of wood. Sampling, cutting and control. Part 1: Sampling, cutting test pieces and expressing the test results.

Normality of sets was verified using Shapiro-Wilkov's test. Subsequently, single-factor analysis of variance was carried out; to assess the interrelations of sets correlation and regression analysis was used.

RESULTS AND DISCUSSION

Moisture

Results of moisture measurements with basic statistic characteristics of combined and all-beech plywoods are given in Table 4.

Table 4. Moisture content of combined and all-beech plywoods

Statistic value	Combined					All-beech			
	8	10	12	15	18	10	12	15	18
n	8	8	8	8	8	8	8	8	8
$\bar{x}$	9.16	8.74	9.68	9.24	9.22	9.78	10.04	10.41	10.18
S	0.76	0.34	0.50	0.13	0.29	0.42	1.599	0.519	0.389
V (%)	8.31	3.84	5.20	1.41	3.12	4.30	15.93	4.986	3.824
Min.	8.62	8.36	8.89	9.07	8.86	9.16	6.393	9.707	9.614
Max.	10.66	9.45	10.42	9.43	9.65	10.49	11.49	11.16	10.75

Table 5. Modulus of elasticity and bending strength of combined plywoods along the grain ($n = 16$)

Statistic value	E (N/mm^2)	f_m (N/mm^2)	ε (mm)	ρ (kg/m^3)	Surface density (kg/m^2)	Thickness (mm)
Foiled exterior combined plywood 8 mm thick						
$\bar{x}$	15,269.08	78.65	3.99	653.81	5.61	8.55
S	1,055.44	4.04	0.40	16.03	0.10	0.08
V (%)	6.91	5.13	10.15	2.45	1.86	0.98
Min.	13,748.53	73.38	3.41	630.93	5.46	8.43
Max.	17,179.38	86.78	4.44	686.45	5.81	8.68
Foiled exterior combined plywood 10 mm thick						
$\bar{x}$	18,519.16	79.90	3.71	10.06	700.52	7.05
S	1,460.38	12.11	0.63	0.10	19.91	0.16
V (%)	7.89	15.16	16.85	0.96	2.84	2.25
Min.	15,714.52	51.84	2.40	9.89	671.02	6.79
Max.	22,411.49	95.16	4.86	10.24	734.91	7.36
Foiled exterior combined plywood 12 mm thick						
$\bar{x}$	12,952.38	54.00	4.42	618.62	7.62	12.33
S	1,718.84	8.93	1.02	10.09	0.13	0.25
V (%)	13.27	16.53	23.04	1.63	1.73	2.00
Min.	10,821.82	35.41	2.62	601.17	7.41	11.97
Max.	17,116.31	62.11	6.57	635.43	7.89	12.87
Foiled exterior combined plywood 15 mm thick						
$\bar{x}$	14,497.44	68.41	7.03	653.45	9.74	14.90
S	713.07	5.18	0.83	9.50	0.18	0.12
V (%)	4.92	7.57	11.86	1.45	1.80	0.79
Min.	12,991.38	61.54	4.55	636.66	9.40	14.73
Max.	16,178.63	76.90	8.03	664.53	10.00	15.06
Foiled exterior combined plywood 18 mm thick						
$\bar{x}$	12,634.15	58.93	7.96	651.85	11.97	18.36
S	578.67	3.36	0.38	22.10	0.41	0.16
V (%)	4.58	5.71	4.81	3.39	3.42	0.87
Min.	11,418.18	51.76	7.38	620.45	11.39	18.21
Max.	13,923.20	63.81	8.59	726.75	13.31	18.85

Table 6. Correlation analysis of combined plywoods along the grain

Variable	Correlations (bending strength)*			Correlations (bending strength)*		
	ρ	surface density	thickness	ρ	surface density	thickness
	8 mm thick			**15 mm thick**		
E	–0.1897	–0.1759	0.3359	–0.0908	–0.1449	0.1627
	p = 0.482	p = 0.515	p = 0.203	p = 0.738	p = 0.592	p = 0.547
f_m	–0.1699	0.0156	0.2879	–0.1154	–0.3785	**–0.6528**
	p = 0.529	p = 0.954	p = 0.280	p = 0.670	p = 0.148	**p = 0.006**
ε	0.3895	0.1720	0.3166	0.3288	0.2262	–0.0903
	p = 0.136	p = 0.524	p = 0.232	p = 0.214	p = 0.400	p = 0.739
	10 mm thick			**18 mm thick**		
E	0.1263	0.0194	–0.3291	0.2303	0.3728	**0.5714**
	p = 0.641	p = 0.943	p = 0.213	p = 0.391	p = 0.155	**p = 0.021**
f_m	–0.1045	–0.1807	–0.1177	0.3486	0.3568	0.0436
	p = 0.700	p = 0.503	p = 0.664	p = 0.186	p = 0.175	p = 0.872
ε	–0.0861	–0.0649	0.0967	0.3409	0.2078	**–0.5114**
	p = 0.751	p = 0.811	p = 0.722	p = 0.196	p = 0.440	**p = 0.043**
	12 mm thick					
E	0.0204	0.1923	0.1469			
	p = 0.940	p = 0.476	p = 0.587			
f_m	0.1107	–0.0575	–0.1341			
	p = 0.683	p = 0.833	p = 0.620			
ε	0.0991	0.0698	–0.0156			
	p = 0.715	p = 0.797	p = 0.954			

*Marked correlations are significant at $p < 0.050$; $n = 16$ (casewise deletion of missing data

Density, strength and modulus of elasticity of plywood sheets

Results of measurements with basic statistic characteristics of density, strength and MOE of combined and all-beech plywoods and results of correlation analysis are given in Tables 4–12. Table 12 is an aggregate table of bending strength and MOE in bending for combined plywoods, Table 13 gives results of the respective correlation analysis. Table 14 is an aggregate table of bending strength and MOE in bending for all-beech plywoods, Table 15 gives results of the respective correlation analysis. Table 16 gives results of correlation analysis for combined and all-beech plywoods. Important relationships are represented in italics. Negative correlation coefficient expresses negative dependence. The value of p given in tables under correlation coefficients expresses probability of the occurrence of a studied phenomenon in the basic set.

Figs. 7–9 show dependences of MOE in bending, bending strength and relative deformation on the sheet thickness in combined plywoods. In Figs. 10 to 12, dependences are given of MOE in bending, bending strength and relative deformation on the sheet density in combined plywoods, in Figs. 13–15 dependences are depicted of MOE in bending, bending strength and relative deformation on the number of plies in combined plywoods. Figs. 16–18 illustrate dependences of MOE in bending, bending strength and relative deformation on the sheet thickness in all-beech plywoods. In Figs. 19–21, dependences are depicted of MOE in bending, bending strength and relative deformation on the sheet density in all-beech plywoods. Figs. 22–24 show dependences of MOE in bending, bending strength

Table 7. Modulus of elasticity and bending strength of combined plywoods across the grain (n = 16)

Statistic value	E (N/mm^2)	f_m (N/mm^2)	ε (mm)	ρ (kg/m^3)	Surface density (kg/m^2)	Thickness (mm)
Foiled exterior combined plywood 8 mm thick						
$\bar{x}$	9,368.89	44.26	3.16	647.42	5.58	8.59
S	952.68	4.55	0.51	24.43	0.22	0.09
V (%)	10.17	10.27	16.27	3.77	3.93	0.99
Min.	7,781.09	32.02	2.25	618.65	5.29	8.43
Max.	11,574.08	53.60	4.09	704.99	6.07	8.74
Foiled exterior combined plywood 10 mm thick						
$\bar{x}$	9,683.37	43.01	4.01	10.01	703.79	7.05
S	892.86	8.54	1.08	0.07	15.58	0.14
V (%)	9.22	19.85	27.07	0.74	2.21	1.98
Min.	7,779.00	24.69	2.18	9.89	669.08	6.67
Max.	11,185.21	56.91	6.22	10.17	735.16	7.29
Foiled exterior combined plywood 12 mm thick						
$\bar{x}$	11,281.88	43.69	3.81	619.69	7.61	12.27
S	1,000.96	7.16	1.08	20.16	0.27	0.18
V (%)	8.87	16.40	28.26	3.25	3.61	1.44
Min.	9,786.09	31.30	2.45	593.77	7.13	12.00
Max.	12,925.91	56.54	6.04	658.97	8.09	12.62
Foiled exterior combined plywood 15 mm thick						
$\bar{x}$	14,435.53	61.09	6.08	656.75	9.81	14.94
S	1,471.21	9.85	1.22	14.14	0.22	0.10
V (%)	10.19	16.12	20.06	2.15	2.26	0.70
Min.	11,343.94	34.35	3.31	631.01	9.40	14.71
Max.	16,562.53	75.54	7.89	690.59	10.35	15.12
Foiled exterior combined plywood 18 mm thick						
$\bar{x}$	17,381.69	62.78	6.10	651.25	11.97	18.38
S	811.79	12.30	2.01	18.16	0.29	0.11
V (%)	4.67	19.59	32.95	2.79	2.46	0.62
Min.	15,766.15	37.08	3.20	628.95	11.58	18.11
Max.	18,699.65	78.33	9.54	690.71	12.51	18.54

and relative deformation on the number of plies in all-beech plywoods.

Fractures of plywoods

The bending tests have demonstrated that both combined and all-beech plywoods of all thicknesses comply with minimum strength values given by DIN 68 705 Teil 3 standard.

In the bending tests, failures occurred mostly in surface layers of the tensile zone (Figs. 28–29) or along the whole thickness of a specimen (Figs. 25 to 27). In combined plywoods 18 mm thick, 75% of failures occurred in the central layer during bending

Table 8. Correlation analysis of combined plywoods across the grain

Variable	Correlations (bending strength)*					
	ρ	surface density	thickness	ρ	surface density	thickness
		8 mm thick			**15 mm thick**	
E	–0.0833	–0.0244	0.2610	0.4749	0.4738	0.0725
	p = 0.759	p = 0.929	p = 0.329	p = 0.063	p = 0.064	p = 0.790
f_m	–0.0609	–0.0283	0.1397	0.4300	0.2625	–0.4790
	p = 0.823	p = 0.917	p = 0.606	p = 0.096	p = 0.326	p = 0.060
ε	–0.3277	–0.3830	–0.1519	0.2032	0.1230	–0.2301
	p = 0.215	p = 0.143	p = 0.574	p = 0.450	p = 0.650	p = 0.391
		10 mm thick			**18 mm thick**	
E	–0.0114	–0.1524	–0.3812	**0.5549**	**0.5834**	–0.1658
	p = 0.967	p = 0.573	p = 0.145	**p = 0.026**	**p = 0.018**	p = 0.539
f_m	–0.1036	–0.2099	–0.2542	**0.6011**	**0.6223**	–0.2158
	p = 0.702	p = 0.435	p = 0.342	**p = 0.014**	**p = 0.010**	p = 0.422
ε	–0.0592	–0.1259	–0.1607	0.3816	0.4199	–0.0415
	p = 0.828	p = 0.642	p = 0.552	p = 0.145	p = 0.105	p = 0.879
		12 mm thick				
E	0.0558	–0.0257	–0.1768			
	p = 0.837	p = 0.925	p = 0.513			
f_m	0.2155	0.1826	–0.0125			
	p = 0.423	p = 0.498	p = 0.963			
ε	**0.5062**	**0.5054**	0.1307			
	p = 0.045	**p = 0.046**	p = 0.629			

*Marked correlations are significant at $p < 0.050$; $n = 16$ (casewise deletion of missing data)

in cross direction. The failures occurred as a result of surmounting the central veneer shear strength (Fig. 30). Fig. 31 depicts failures in the central zone due to the central veneer defect.

The results of correlation and regression analysis for particular thicknesses and directions of the acting force as related to density, surface density and thickness proved the relationships only in a small number of measurements.

Correlation analysis has demonstrated more relationships in aggregate sets for particular types of plywoods (Tabs. 13 and 14). Table 13 demonstrates

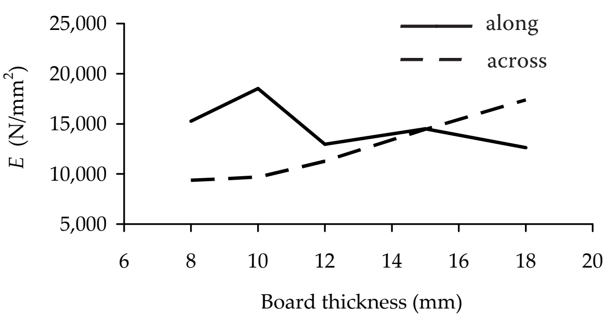

Fig. 7. Dependence of modulus of elasticity on the sheet thickness in combined plywoods

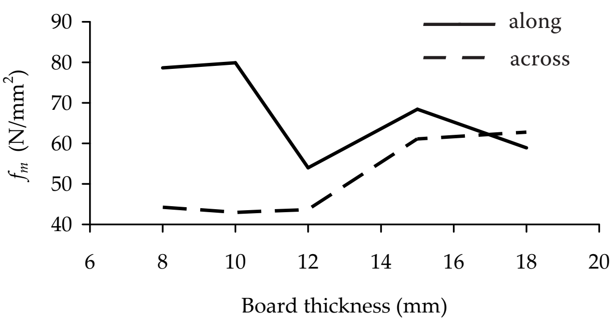

Fig. 8. Dependence of bending strength on the sheet thickness in combined plywoods

Table 9. Modulus of elasticity and bending strength of all-beech plywoods along the grain (n = 8)

Statistic value	E (N/mm²)	f_m (N/mm²)	ε (mm)	ρ (kg/m³)	Surface density (kg/m²)	Thickness (mm)
Foiled exterior all-beech plywood 10 mm thick						
$\bar{x}$	21,856.08	95.23	4.04	824.87	8.12	9.84
S	1,577.29	7.68	0.35	20.80	0.19	0.04
V (%)	7.22	8.07	8.67	2.52	2.33	0.36
Min.	19,536.39	86.12	3.56	785.38	7.75	9.78
Max.	23,919.32	106.12	4.60	847.27	8.35	9.88
Foiled exterior all-beech plywood 12 mm thick						
$\bar{x}$	18,456.72	75.81	5.11	695.83	8.48	12.18
S	1,546.69	6.60	0.80	9.49	0.14	0.06
V (%)	8.38	8.71	15.58	1.36	1.67	0.53
Min.	17,195.19	67.19	4.18	681.37	8.29	12.08
Max.	22,083.32	84.92	6.31	707.63	8.68	12.28
Foiled exterior all-beech plywood 15 mm thick						
$\bar{x}$	21,968.82	86.74	5.68	753.25	11.53	15.30
S	611.09	4.00	0.37	12.32	0.15	0.12
V (%)	2.78	4.61	6.59	1.64	1.26	0.81
Min.	21,045.54	79.01	5.06	728.59	11.26	15.10
Max.	22,646.43	92.38	6.24	769.71	11.69	15.46
Foiled exterior all-beech plywood 18 mm thick						
$\bar{x}$	21,015.43	78.07	5.96	742.48	13.55	18.25
S	785.73	8.34	0.97	9.34	0.06	0.24
V (%)	3.74	10.68	16.28	1.26	0.44	1.31
Min.	19,957.49	59.21	4.12	732.56	13.48	17.94
Max.	22,531.44	87.61	7.27	755.90	13.63	18.60

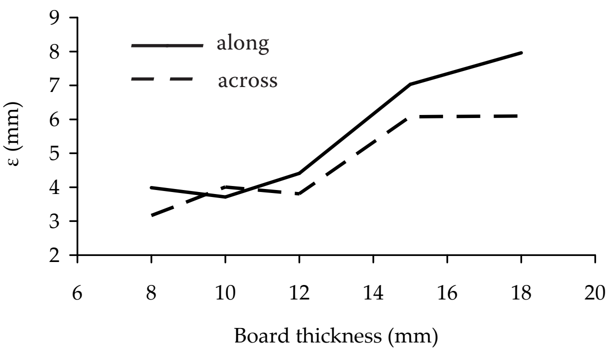

Fig. 9. Dependence of relative deformation on the sheet thickness in combined plywoods

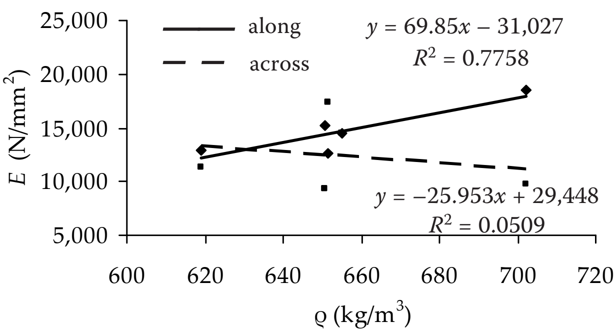

Fig. 10. Dependence of modulus of elasticity on the sheet density in combined plywoods

Table 10. Modulus of elasticity and bending strength of all-beech plywoods across the grain (n = 8)

Statistic value	E (N/mm^2)	f_m (N/mm^2)	ε (mm)	ρ (kg/m^3)	Surface density (kg/m^2)	Thickness (mm)
Foiled exterior all-beech plywood 10 mm thick						
$\bar{x}$	12,493.68	77.50	6.30	806.96	8.03	9.95
S	400.35	1.70	0.46	11.37	0.08	0.06
V (%)	3.20	2.20	7.32	1.41	1.01	0.65
Min.	12,128.64	75.23	5.63	790.09	7.90	9.83
Max.	13,212.22	80.54	6.95	822.98	8.15	10.02
Foiled exterior all-beech plywood 12 mm thick						
$\bar{x}$	9,774.69	55.68	7.39	669.55	8.15	12.18
S	504.82	3.60	1.17	113.00	1.38	0.08
V (%)	5.16	6.47	15.78	16.88	16.94	0.62
Min.	8,751.38	51.15	5.88	391.33	4.75	12.01
Max.	10,212.80	61.65	9.12	721.27	8.79	12.25
Foiled exterior all-beech plywood 15 mm thick						
$\bar{x}$	14,053.18	70.71	8.18	751.23	11.60	15.44
S	612.86	1.43	0.31	15.91	0.41	0.24
V (%)	4.36	2.03	3.79	2.12	3.50	1.53
Min.	13,247.14	68.52	7.88	719.09	10.87	15.12
Max.	15,082.34	73.03	8.65	765.94	12.03	15.79
Foiled exterior all-beech plywood 18 mm thick						
$\bar{x}$	13,774.44	65.62	9.48	747.97	13.57	18.15
S	1,027.94	7.43	1.95	13.87	0.23	0.09
V (%)	7.46	11.32	20.59	1.85	1.73	0.52
Min.	11,493.28	51.16	6.73	729.48	13.36	18.03
Max.	14,693.31	72.42	11.64	772.96	14.08	18.31

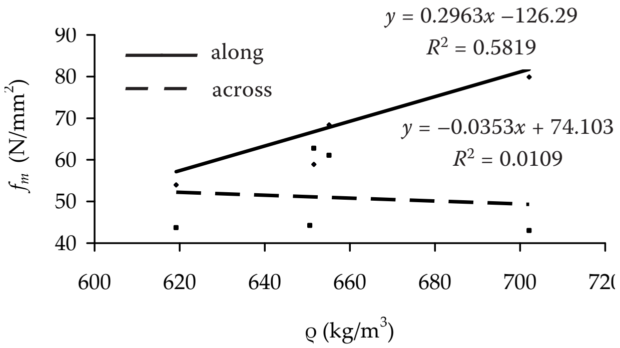

Fig. 11. Dependence of bending strength on the sheet density in combined plywoods

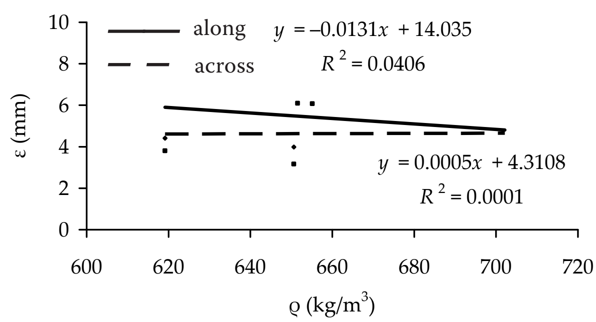

Fig. 12. Dependence of relative deformation on the sheet density in combined plywoods

Table 11. Correlation analysis of all-beech plywoods along and across the grain

Variable	Correlations (bending strength)*					
	along the grain			across the grain		
	ρ	surface density	thickness	ρ	surface density	thickness
10 mm thick						
E	0.5949	0.5956	−0.3114	−0.1047	−0.0477	0.1535
	p = 0.120	p = 0.119	p = 0.453	p = 0.805	p = 0.911	p = 0.717
f_m	0.6810	0.6755	−0.3962	−0.0176	−0.1235	−0.1523
	p = 0.063	p = 0.066	p = 0.331	p = 0.967	p = 0.771	p = 0.719
ε	0.1491	0.1572	−0.0284	0.1904	−0.0049	−0.4233
	p = 0.725	p = 0.710	p = 0.947	p = 0.651	p = 0.991	p = 0.296
12 mm thick						
E	−0.3503	−0.2707	0.0515	**−0.7427**	**0.8685**	−0.0919
	p = 0.395	p = 0.517	p = 0.904	**p = 0.035**	**p = 0.005**	p = 0.829
f_m	−0.5211	−0.5379	0.3474	−0.1001	0.3109	0.3853
	p = 0.185	p = 0.169	p = 0.399	p = 0.814	p = 0.453	p = 0.346
ε	−0.3851	−0.3545	0.1205	−0.5312	−0.2477	0.5642
	p = 0.346	p = 0.389	p = 0.776	p = 0.175	p = 0.554	p = 0.145
15 mm thick						
E	0.1701	0.3343	0.1915	**0.7210**	**−0.7519**	**0.7290**
	p = 0.687	p = 0.418	p = 0.650	**p = 0.044**	**p = 0.031**	**p = 0.040**
f_m	0.0740	0.3904	0.4804	0.3757	0.4095	0.4268
	p = 0.862	p = 0.339	p = 0.228	p = 0.359	p = 0.314	p = 0.292
ε	0.3346	0.5457	0.2039	−0.4460	−0.5102	−0.5444
	p = 0.418	p = 0.162	p = 0.628	p = 0.268	p = 0.196	p = 0.163
18 mm thick						
E	0.2457	−0.4636	−0.3931	−0.2500	0.3006	0.1111
	p = 0.557	p = 0.247	p = 0.335	p = 0.550	p = 0.469	p = 0.793
f_m	0.3890	−0.5997	−0.5791	0.2650	0.2287	−0.1808
	p = 0.341	p = 0.116	p = 0.133	p = 0.526	p = 0.586	p = 0.668
ε	0.1754	−0.6797	−0.4012	0.4068	0.2692	−0.5554
	p = 0.678	p = 0.064	p = 0.325	p = 0.317	p = 0.519	p = 0.153

*Marked correlations are significant at $p < 0.050$; $n = 16$ (casewise deletion of missing data)

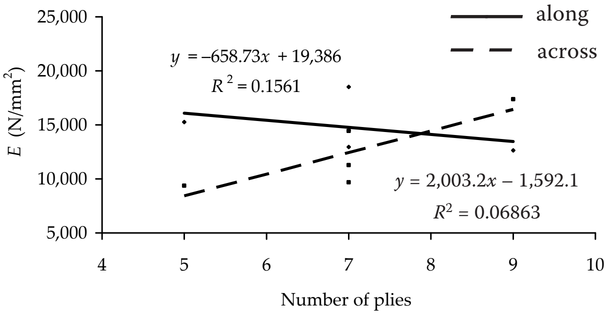

Fig. 13. Dependence of modulus of elasticity on the number of plies in combined plywoods

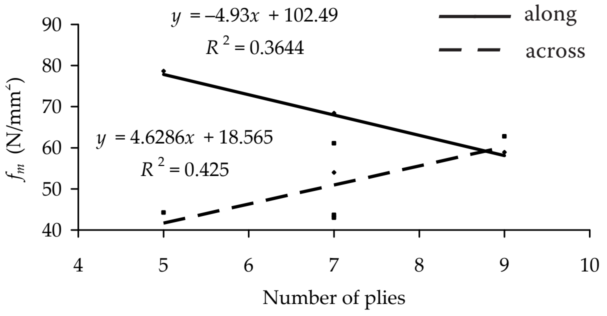

Fig. 14. Dependence of bending strength on the number of sheet plies in combined plywoods

Table 12. Aggregate table of bending strength and modulus of elasticity in bending for combined plywoods

Thickness (mm)	Number of plies	w (%)	Surface density (kg/m^2)	ρ (kg/m^3)	$\varepsilon_{\parallel}$ (mm)	$\varepsilon_{\perp}$ (mm)	$f_{m\parallel}$ (N/mm^2)	$f_{m\perp}$ (N/mm^2)	$E_{\parallel}$ (N/mm^2)	$E_{\perp}$ (N/mm^2)
8	5	9.16	5.59	650.61	3.99	3.16	78.65	44.26	15,269.08	9,368.89
10	7	8.74	7.05	702.16	3.71	4.01	79.90	43.01	18,519.16	9,683.37
12	7	9.68	7.61	619.15	4.41	3.81	54.00	43.69	12,952.38	11,281.88
15	7	9.24	9.77	655.10	7.03	6.08	68.41	61.09	14,497.44	14,435.53
18	9	9.22	11.97	651.55	7.96	6.10	58.93	62.78	12,634.15	17,381.69

Table 13. Correlation analysis – combined plywoods

Variable	Correlations (summary)*				
	thickness	No. of layer	w	surface density	ρ
E_{along}	**0.9479**	0.7245	0.1824	**0.9502**	–0.2015
	***p* = 0.014**	p = 0.166	p = 0.769	***p* = 0.013**	p = 0.745
ε_{across}	**0.9325**	0.7592	0.0200	**0.9402**	0.0106
	***p* = 0.021**	p = 0.137	p = 0.975	***p* = 0.017**	p = 0.988
$f_{m\,along}$	–0.6510	–0.6037	–0.8295	–0.5791	0.7628
	p = 0.234	p = 0.281	p = 0.082	p = 0.306	p = 0.134
$f_{m\,across}$	0.9019	0.6519	0.0805	**0.9109**	–0.1045
	p = 0.036	p = 0.233	p = 0.898	***p* = 0.032**	p = 0.867
E_{along}	–0.6172	–0.3950	–0.8486	–0.5535	**0.8808**
	p = 0.267	p = 0.510	p = 0.069	p = 0.333	***p* = 0.048**
E_{across}	**0.9833**	0.8285	0.2222	**0.9846**	**–0.2257**
	***p* = 0.003**	p = 0.083	p = 0.719	***p* = 0.002**	p = 0.715

*Marked correlations are significant at $p < 0.05000$; $n = 5$ (casewise deletion of missing data)

that relationships of bending strength or modulus of elasticity show a reversible character of development along and across the grain in the upper veneer.

The trend is also evident from Figs. 18 and 19 where an increase in bending strength or MOE in bending across the grain occurs while there is a decrease in the values along the grain. The fact is caused by the construction of plywoods where spruce veneers 3.5 mm thick are used as the second outer plies in plywoods 15 and 18 mm thick. These

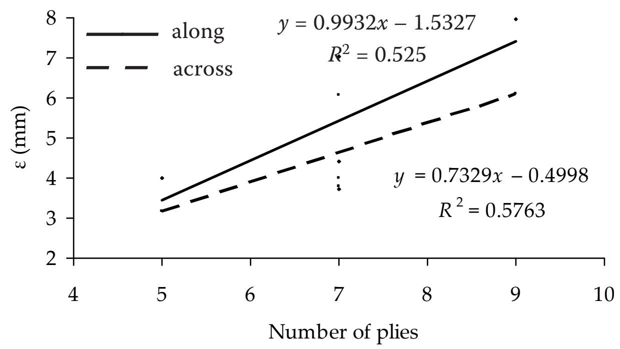

Fig. 15. Dependence of relative deformation on the number of sheet plies in combined plywoods

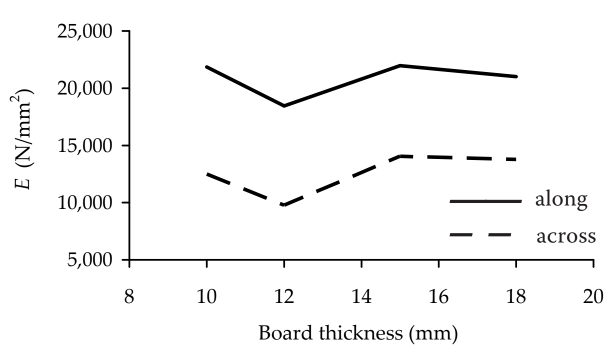

Fig. 16. Dependence of MOE on the sheet thickness in all-beech plywoods

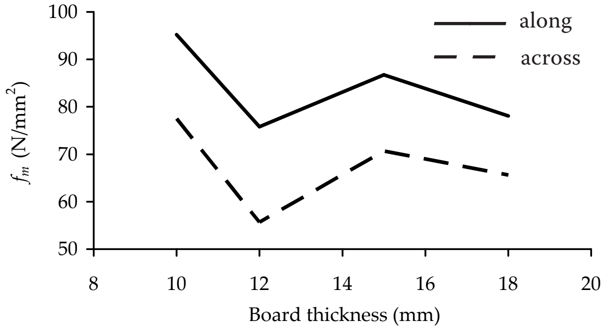

Fig. 17. Dependence of bending strength on the sheet thickness in all-beech plywoods

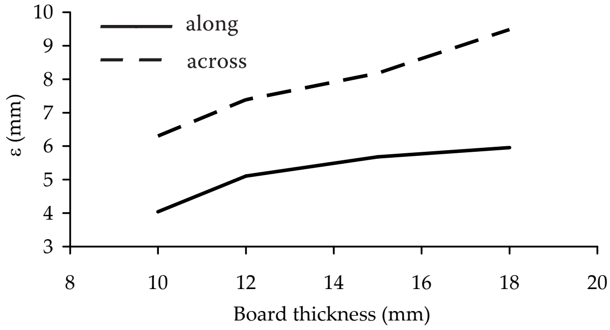

Fig. 18. Dependence of relative deformation on the sheet thickness in all-beech plywoods

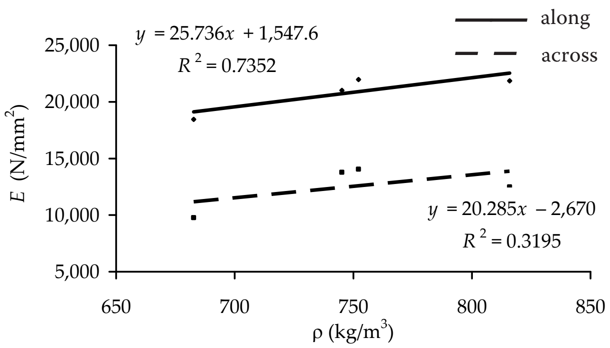

Fig. 19. Dependence of MOE on the sheet density in all-beech plywoods

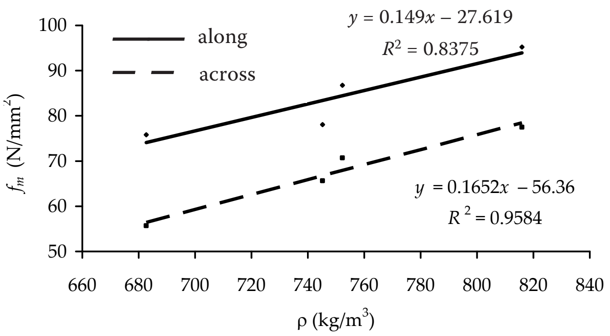

Fig. 20. Dependence of bending strength on the sheet density in all-beech plywoods

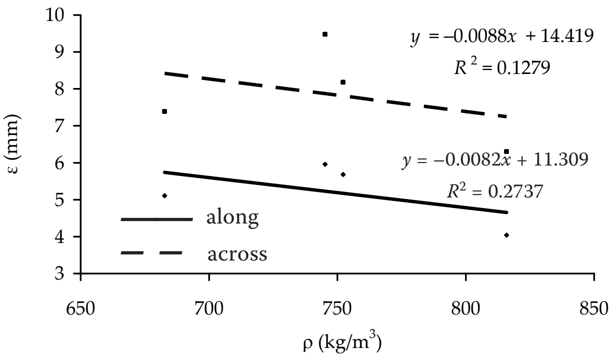

Fig. 21. Dependence of relative deformation on the sheet density in all-beech plywoods

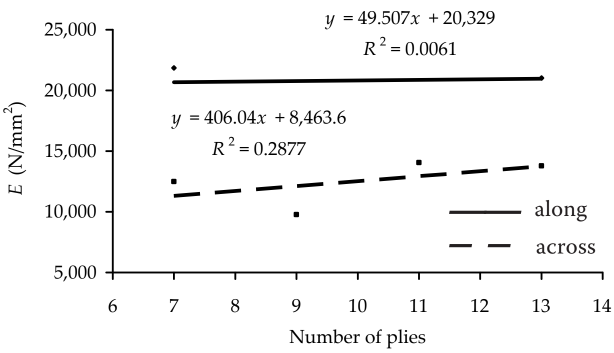

Fig. 22. Dependence of MOE on the number of sheet plies in all-beech plywoods

plies take over the majority of strength in bending stress across the grain and vice versa only surface beech veneers 1.5 mm thick are most stressed along the grain.

Table 15 of correlation analysis calculated for all thicknesses and types of plywoods shows a strong dependence of bending strength and MOE on the sheet density.

Table 14. Aggregate table of bending strength and MOE in bending for all-beech plywoods

Thickness (mm)	Number of plies	*w* (%)	Surface density (kg/m^2)	ρ (kg/m^3)	$\varepsilon_{\parallel}$ (mm)	$\varepsilon_{\perp}$ (mm)	$f_{m\parallel}$ (N/mm^2)	$f_{m\perp}$ (N/mm^2)	$E_{\parallel}$ (N/mm^2)	$E_{\perp}$ (N/mm^2)
10	7	9.78	8.07	815.91	4.04	6.30	95.23	77.50	21,856.08	12,493.68
12	9	10.04	8.32	682.69	5.11	7.39	75.81	55.68	18,456.72	9,774.69
15	11	10.41	11.56	752.24	5.68	8.18	86.74	70.71	21,968.82	14,053.18
18	13	10.18	13.56	745.23	5.96	9.48	78.07	65.62	21,015.43	13,774.44

Table 15. Correlation analysis of an all-beech plywood

Variable	Correlations (summary)*				
	thickness	No. of plies	w	surf.ace ensity	ρ
E_{along}	0.9360	0.9631	0.8742	0.8671	–0.5232
	p = 0.064	p = 0.037	p = 0.126	p = 0.133	p = 0.477
ε_{across}	0.9927	0.9959	0.7142	0.9481	–0.3576
	p = 0.007	p = 0.004	p = 0.286	p = 0.052	p = 0.642
$f_{m\ along}$	–0.5323	–0.5904	–0.3890	–0.3489	0.9151
	p = 0.468	p = 0.410	p = 0.611	p = 0.651	p = 0.085
$f_{m\ across}$	–0.2154	–0.2894	–0.2261	–0.0115	0.9790
	p = 0.785	p = 0.711	p = 0.774	p = 0.989	p = 0.021
E_{along}	0.1466	0.0782	0.1408	0.3438	0.8575
	p = 0.853	p = 0.922	p = 0.859	p = 0.656	p = 0.143
E_{across}	0.5920	0.5364	0.4844	0.7417	0.5652
	p = 0.408	p = 0.464	p = 0.516	p = 0.258.	p = 0.435

*Marked correlations are significant at $p < 0.050$; $n = 5$ (casewise deletion of missing data)

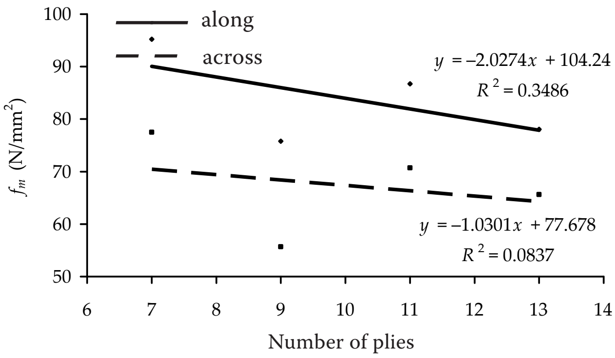

Fig. 23. Dependence of bending strength on the number of sheet plies in all-beech plywoods

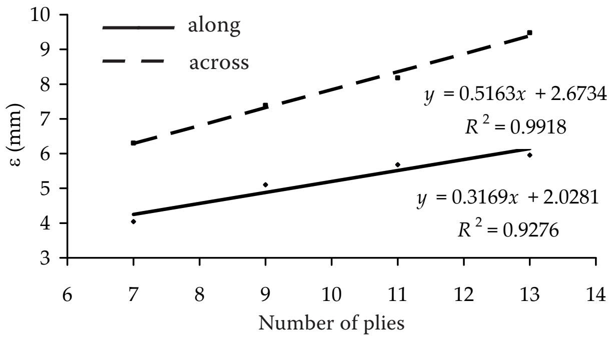

Fig. 24. Dependence of relative deformation on the number of sheet plies in all-beech plywoods

Fig. 25. Fracture along the height of the specimen in a combined plywood 18 mm thick

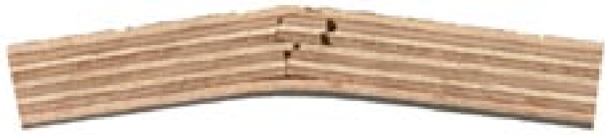

Fig. 27. Fibrous fracture along the height of the specimen in a beech plywood 15 mm thick

Fig. 26. Fibrous fracture along the height of the specimen in a combined plywood 18 mm thick

Fig. 28. Rupture of fibres in the tensile zone of the specimen in a combined plywood 15 mm thick

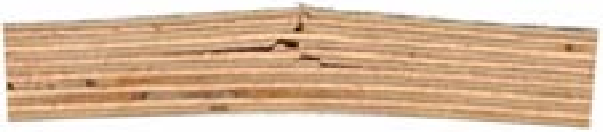

Fig. 29. Rupture of fibres in the tensile zone of the specimen in a beech plywood 18 mm thick

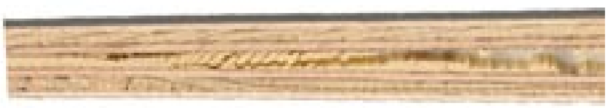

Fig. 30. Failure in the central zone due to shear stress in a combined plywood 18 mm thick

Fig. 31. Failure in the central zone due to shear stress caused by the defect of a central veneer in a combined plywood 10 mm thick

If we compare bending strength and MOE in bending between all-beech and combined plywoods (Figs. 32 and 33) we can conclude that all-beech plywoods reach higher values than combined plywoods. It is given by the fact that beech wood shows twice higher bending strength than spruce wood.

Table 16. Correlation analysis for combined and all-beech plywoods

Variable	Correlations (summary for all boards)*					
	ε_{along}	ε_{across}	$f_{m\ along}$	$f_{m\ across}$	E_{along}	E_{across}
Thickness	**0.8767**	**0.6996**	–0.3457	0.4595	–0.0482	**0.8506**
	***p* = 0.002**	***p* = 0.036**	*p* = 0.362	*p* = 0.213	*p* = 0.902	***p* = 0.004**
Number of plies	0.4439	**0.9078**	0.1050	0.5127	0.4926	0.4684
	p = 0.231	***p* = 0.001**	*p* = 0.788	*p* = 0.158	*p* = 0.178	*p* = 0.203
w	0.0949	**0.7693**	0.2852	0.5803	0.5789	0.1638
	p = 0.808	***p* = 0.015**	*p* = 0.457	*p* = 0.101	*p* = 0.102	*p* = 0.674
Surface density	**0.7562**	**0.8377**	–0.0779	0.6207	**0.2309**	**0.8070**
	***p* = 0.018**	***p* = 0.005**	*p* = 0.842	*p* = 0.074	*p* = 0.550	***p* = 0.009**
ρ	–0.2229	0.5525	**0.8725**	**0.7517**	**0.9189**	0.0795
	p = 0.564	*p* = 0.123	***p* = 0.002**	***p* = 0.019**	***p* = 0.000**	*p* = 0.839

*Marked correlations are significant at $p < 0.050$; $n = 9$ (casewise deletion of missing data)

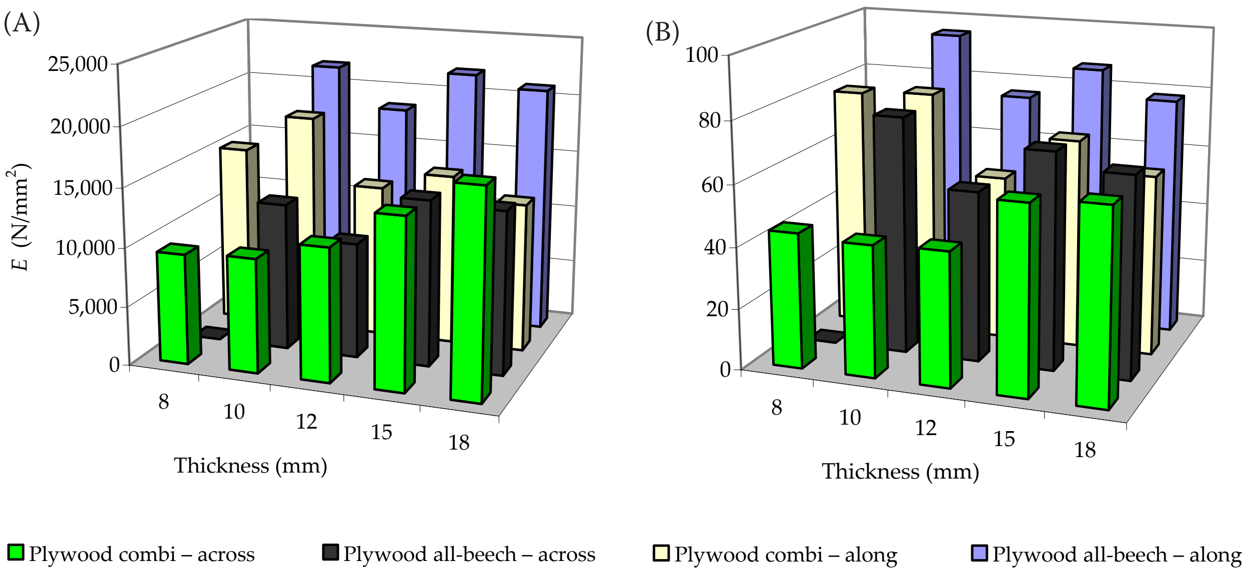

Fig. 32. Comparison of MOE in bending (A) and bending strength (B) between combined and all-beech plywoods

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Posouzení pevnosti v ohybu a modulu pružnosti v ohybu vodovzdorných fóliovaných překližek v závislosti na jejich konstrukci

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ABSTRAKT: Článek shrnuje výsledky institucionálního výzkumu zaměřeného na posouzení pevnosti v ohybu a modulu pružnosti v ohybu vodovzdorných fóliovaných kombinovaných a celobukových překližek v závislosti na jejich konstrukci. Byl zkoumán vztah konstrukce překližek a vybraných fyzikálních a mechanických vlastností. U zkoumaných desek byla analyzována ve vzájemných souvislostech vlhkost, hustota, pevnost v ohybu a modul pružnosti v ohybu podél a napříč vláken vrchní dýhy. Veškerá měření byla provedena na vodovzdorných překližkách s povrchovou úpravou fenolformaldehydovou fólií kombinovaných o tloušťce 8, 10, 12 a 15 mm a celobukových o tloušťce 10, 12, 15 a 18 mm. Konstrukce překližek významným způsobem ovlivňuje kvalitu, která je určována zejména pevností v ohybu a modulem pružnosti v ohybu. Použitím regresní analýzy byly prokázány závislosti – zejména to, že s rostoucí vlhkostí překližek klesá pevnost v ohybu a se zvyšující se hustotou roste pevnost v ohybu a modul elasticity. Stejný trend se prokázal i v souvislosti se zvyšujícím se počtem dýh překližovaných desek. Korelační metodou byly statisticky testovány vzájemné kombinace závislostí uvedených vlastností.

Klíčová slova: překližka; hustota; plošná hmotnost; vlhkost; tloušťka; pevnost v ohybu; modul pružnosti v ohybu; dýha; statistická analýza

Překližované desky jsou definovány jako desky se vzájemně slepenými vrstvami, přičemž směr vláken sousedních vrstev je na sebe kolmý. Ve všeobecnosti jsou vnější a vnitřní vrstvy na obou stranách vzhledem ke střední (případně středové vrstvě) symetricky uspořádány.

Výroba překližovaných desek patří k nejmladším odvětvím dřevozpracujícího průmyslu. Překližované desky se během času dostaly na jedno z vedoucích míst trhu s velkoplošnými materiály. Používají se v mnoha odvětvích lidské činnosti, například ve strojírenství, v textilním průmyslu, ve výrobě nábytku, v dopravě, v průmyslové a ve stavební výrobě apod.

Překližované materiály, které řadíme spolu s materiály aglomerovanými k materiálům velkoplošným, se vyrábějí lisováním souborů dýh nanesených syntetickým lepidlem za tepla a za spolupůsobení tlaku.

Proti aglomerovaným materiálům, tj. třískovým a vláknitým deskám, mají určité výhody. Jsou podstatně lehčí (mají nižší hustotu), vykazují vyšší hodnoty jednotlivých mechanických a fyzikálních vlastností. Jejich hlavní výhoda spočívá v tom, že si uchovávají vzhled přírodního dřeva. Překližované desky se dají rovněž vyrábět ve formě tvarovaných výlisků. Ve všeobecnosti se dají jednoduše povrchově upravovat. Podle účelu použití – za přídavku speciálních typů syntetických lepidel nebo fóliováním speciálními fóliemi – se dají překližované desky vyrábět jako vodovzdorné.

Největší uplatnění nacházejí překližované desky (nevodovzdorné) v nábytkářském průmyslu. Ve stavebnictví se naopak používají překližované desky vodovzdorné. Stavebnictví používá překližované desky i pro konstrukci a výrobu podlah, obkladů, nosných stěn, lamelových konstrukcí apod. V dopravě mají překližované desky použití při výrobě železničních vagonů, autobusů, tramvají, nákladních vozů, lodí apod.

Překližované desky se rozdělují podle konstrukce na překližky (truhlářské, stavební, obalové, letecké, z vrstveného dřeva), jádrové desky (laťovky, dýhovky), složené desky (voštinové, velitové desky) a dále podle tvaru na ploché a tvarové.

Jejich další rozdělení je možné podle hlavních kvalitativních znaků, tj. podle životnosti (pro použití ve venkovním a ve vnitřním suchém prostředí), mechanických vlastností, vzhledu povrchu, způsobu úpravy povrchu (nebroušené, broušené, povrchově upravené, opláštěné).

Kvalita překližovaných desek je posuzována podle mnoha kritérií a znaků. Obecně lze konstatovat, že překližované desky se třídí podle platných norem. Musí splňovat požadavky na rozměrovou přesnost (formáty i přířezy), kvalitu lepení, vnější kvalitativní znaky, fyzikální a mechanické vlastnosti, speciální požadavky zákazníků (snížené uvolňování formaldehydu, zvýšená požární odolnost, odolnost vůči plísním, houbám a hmyzu).

Pevnost v ohybu a modul pružnosti v ohybu překližovaných materiálů ovlivňuje celá řada faktorů – druh dřeviny, kvalita dřeviny, vlhkost dřeva, hustota dřeva, struktura dřeva, teplota, počet vrstev, použité lepidlo a trvalé zatížení.

Cílem práce bylo posouzení pevnosti v ohybu a modulu pružnosti vodovzdorných fóliovaných překližek v závislosti na jejich konstrukci.

Zkoušky byly prováděny na fóliovaných vodovzdorných překližovaných deskách s protiskluzovou úpravou, a to dvou typů konstrukce. V souladu s normami EN 326-1a EN 325 byly sestaveny nářezové plány.

Jednotlivé fyzikální a mechanické vlastnosti překližovaných desek byly zjišťovány podle následujících norem:

– ČSN EN 310 Stanovení modulu pružnosti v ohybu a pevnosti v ohybu
– ČSN EN 322 Desky ze dřeva – Zjišťování vlhkosti
– ČSN EN 323 Desky ze dřeva – Zjišťování hustoty
– ČSN EN 325 Stanovení rozměrů zkušebních těles
– ČSN-EN 326-1 Desky ze dřeva. Odběr vzorků, nařezávání a kontrola. Část 1: Odběr vzorků, nařezávání zkušebních těles a vyjádření výsledků zkoušek.

Normalita souborů byla ověřena pomoci Shapiro-Wilkovova testu. Následně byla provedena jednofaktorová analýza rozptylu a pro posouzení vzájemných závislostí souborů korelační a regresní analýza.

Provedené ohybové zkoušky prokázaly, že překližky kombi i celobukové všech tlouštěk splňují minimální hodnoty pevnosti dané normou DIN 68 705, Teil 3.

Při ohybových zkouškách docházelo k porušení většinou na povrchových vrstvách tahové zóny (obr. 28 až 29) anebo po celé tloušťce vzorku (obr. 25–27). U kombinovaných překližek o tloušťce 18 mm při ohybu v příčném směru došlo v 75 % k porušení ve střední vrstvě vzniklé překonáním smykové pevnosti střední dýhy (obr. 30). Na obr. 31 je patrné porušení ve středové zóně vlivem vady střední dýhy.

Z výsledků korelační a regresní analýzy pro jednotlivé tloušťky a směry působení síly se dependencemi na hustotě, plošné hmotnosti a tloušťce podařilo tyto závislosti dokázat jen u velice mála měření.

Korelační analýza u souhrnných souborů pro jednotlivé typy překližek nám prokázala více závislosti (tab. 13 a 14). V tab. 13 je zajímavé, že závislosti pevnost, resp. modul pružnosti mají obrácený charakter vývoje v podélném a příčném směru vláken horní dýhy. Teto trend je patrný i z obr. 18 a 19, kde dochází k nárůstu pevnosti v ohybu, resp. modulu pružnosti v ohybu v příčném směru a k poklesu hodnot v podélném směru. Tato skutečnost je způsobena konstrukcí překližek, kde jsou u tlouštěk 15 mm a 18 mm použity jako druhé vnější vrstvy smrkové dýhy o tloušťce 3,5 mm. Ty přebírají většinu pevnosti při namáhání na ohyb v příčném směru překližky a naopak v podélném směru jsou nejvíce namáhány jen povrchové bukové dýhy o tloušťce 1,5 mm.

Z tab. 15 korelační analýzy vypočtené za všechny tloušťky a typy desek je patrná silná závislost pevnosti a modulu pružnosti na hustotě desky.

Porovnáním pevnosti v ohybu a modulů pružnosti ohybu mezi celobukovými a kombinovanými překližkami (obr. 32) dojdeme k očekávanému závěru, že celobukové překližky dosahují vyšších hodnot než překližky kombi, protože dřevo buku má dvakrát větší pevnost v ohybu než dřevo smrkové.

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