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MOISTURE-CONTENT-RELATED STABILITY OF BEECH PLYWOOD AND PARTICLE BOARD BEAMS LOADED IN BUCKLING

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ABSTRACT

Performance of beams made of beech plywood and of beech particle boards was tested over the whole buckling range (long, intermediate and short columns), at two extreme moisture contents. There were detected functional relations for critical stress σ_{cr} corresponding to the particular buckling conditions. The moisture content was recognised as an important factor influencing the critical stress in the tested wooden materials over the whole buckling range.

Key words: buckling, wood-based beams, plywood, particle boards, moisture content.

INTRODUCTION

The stability of beams and columns produced of wooden materials and loaded in buckling significantly depends on several factors (slenderness ratio, mode of end fixing, mechanical properties of the loaded element, initial curvature, cross-section shape, load eccentricity, etc. (GERE and TIMOSHENKO 1984, HOVORKOVÁ and KÚDELA 2008, KÚDELA and HOVORKOVÁ 2008, KURJATKO *et al*. 2010, MURAWSKI 2003).

In case of wooden materials, it is also necessary to consider other agents connected with the nature of these materials (structural heterogeneity and properties across the element's cross-section, internal stress state, moisture content, etc.). These factors can equally have an important influence on the core physical and mechanical properties and they have also a considerable impact on the buckling-response performance of beams made of these materials (KÚDELA and HOVORKOVÁ 2007, KÚDELA and ŠTEFKA 2009).

One of the most important factors is wood moisture content. The amount of data on influence of moisture content is not big, with most of them concerning natural wood only and, moreover, manifesting inconsistencies. Roš and Brunner (KOLLMANN and CÔTÉ 1968) state that moisture content has not important influence on critical stress values in long columns. These authors also report significant decrease of buckling strength with increasing moisture content for medium long columns. This change was the most conspicuous in case of short columns, which is in accord with the former statements.

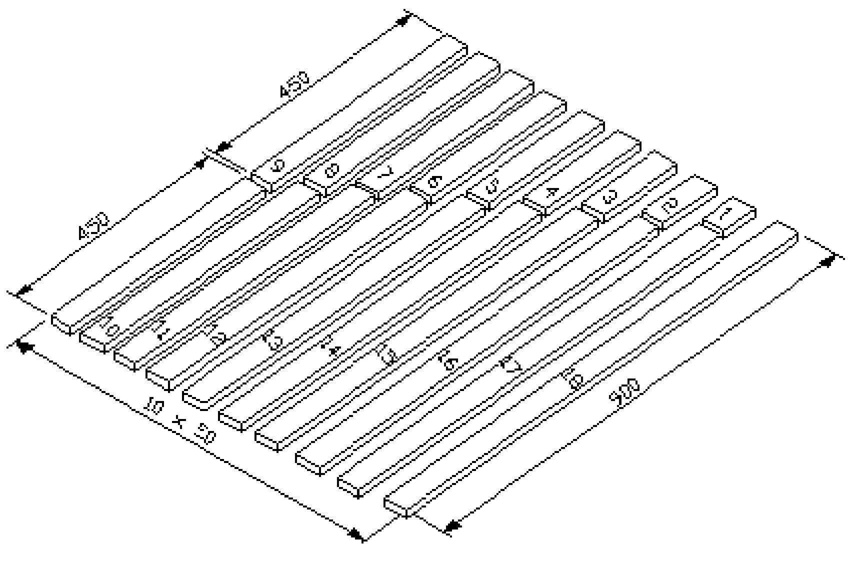
Neither Tetmayer (KOLLMANN and CÔTÉ 1968) considered the influence of moisture content on buckling strength important. On the other hand, Fisher and Kühn (DUTKO *et al*. 1976) confirmed an unambiguous significant influence of wood moisture content on wood buckling strength. POŽGAJ *et al.* (1997) report moisture-related variance in critical stress also for long columns and they also point at changes in the slenderness ratio λ_M with changing moisture content. KÚDELA and SLANINKA (1999), KÚDELA (2006) observed that the buckling strength of spruce wood decreased with increasing moisture content in all three column types: short, medium long and long. In case of OSB boards, there has also been confirmed that moisture content exerted a significant influence over the whole buckling range (KÚDELA and HOVORKOVÁ 2010). The area of medium long columns was found to extend at costs to the long columns area. The results obtained by POŽGAJ (1979), KÚDELA and KÚDELOVÁ (1989) suggest that the moisture-related variation in the buckling strength of PB boards may differ from the massive wood.

The aim of this work was to carry out experiments for investigating the performance of columns made of beech plywood and of beech particle boards, loaded in buckling at two extreme moisture contents.

MATERIALS AND METHODS

The experiments were carried out with a commercially produced seven-layer beech plywood with a thickness of 10 mm and a with beech wood particle board, thick 8 mm. In both cases, we used a urea-formaldehyde glue.

Each of these two materials was represented with three large-sized plates. The samples were cut by four from each plate. Subsequently, these samples were cut to the test specimens (Fig. 1). The thickness of the specimens was determined by the thickness of the plate, the width was 50 mm, the length varied from 50 to 900 mm, with a step of 50 mm. The test specimens dimensions were designed in such a way as to cover all the three buckling intervals (long, medium and short columns). Before the measurement of buckling strength, one group of specimens had been conditioned in an environment with a relative air humidity of φ = 65 % and temperature t = 20 ^{o}C, and the other group was stored over the water surface in a closed vessel (φ ≅ 100 %, t = 20 ^{o}C).



Obr. 1 The cutting design for the test specimens.

Buckling strength was determined using the values of the critical stress σ_{cr}, and it was tested for two end restrains: pinned (cylindrical joints) fixed supports (Fig. 2).

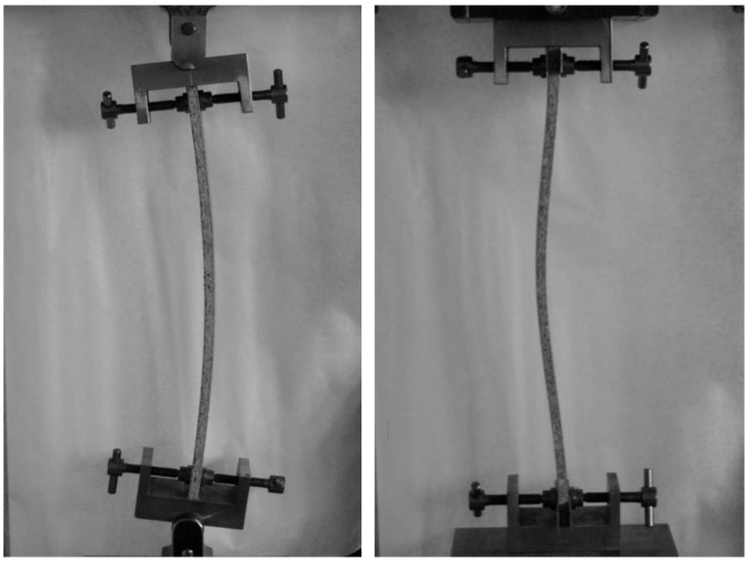


Fig. 2 Restraining of ends: a) pinned, b) supports fixed.

In both cases of columns end supports, the test specimens were loaded in compression centrically, parallel to the board's surface, up to the loss of their stability. The critical stress was calculated according to the equation

$$\sigma_{cr} = \frac{F_{cr}}{A}, \quad (1)$$

where F_{cr} is experimentally measured critical force and S is the surface of the specimen under the force impact.

There were experimentally determined the values of critical stress calculated according to the Eq (1) and these were compared with the critical stress values calculated according to the existing theoretic models (KÚDELA and SLANINKA 2002).

There were also performed experiments (commonly used methods) for determining values of moisture content and density of plywood and particle board and their stress characteristics in compression parallel to the board (proportional limit, modulus of elasticity) necessary to perform the buckling-related calculations.

RESULTS AND DISCUSSION

For the tested plywood and PB boards, we obtained experimental values of σ_{cr} for the whole buckling area at moisture content values 10 and 22 %.

We also determined experimentally the stress characteristics necessary for calculations of critical stress according to the individual models. The values of these characteristics, together with the values of density and moisture content are in Table 1.

Tab. 1 Basic statistic characteristics of moisture content, density and selected stress characteristics for plywood and particle boards, in compression parallel to the board.

Basic statistical characteristics	**Moisture content** m **[%]**	**Density** ρ **[kg·m⁻³]**	**Strength** σ_s **[MPa]**	**Proportional limit** σ_{pl} **[MPa]**	**Modulus of elasticity** E **[MPa]**
			Plywood		
$\bar{x}$	10.0	803	45.0	23.8	8227
s	0.74	16	4.3	4.7	939
n	30	108	30	30	30
$\bar{x}$	22.0		22.8	13.5	6316
s	0.5	–	1.4	1.2	949
n	36		36	36	36
			PB		
$\bar{x}$	9.0	771	13.0	8.1	2450
s	0.22	29	0.8	1.2	168
n	30	108	30	30	30
$\bar{x}$	20.0		7.2	5.5	1209
s	0.4	–	0.7	0.6	237
n	36		36	36	36

Using the equation

$$\lambda_L = \sqrt{\frac{C\pi^2 E_L}{\sigma_{pl}}} \tag{2}$$

we determined the range of long columns complying with the relation $\sigma_{cr} \leq \sigma_{pl}$, and the experimental results obtained in this area were compared with the values calculated according to the Euler equation

$$\sigma_{cr} = \frac{C\pi^2 E_L}{\lambda^2}, \tag{3}$$

where λ is column slenderness, λ_L is boundary slenderness value between the range of long and intermediate columns, σ_{pl} is the proportionality limit in compression parallel to grain and E_l is the Young modulus of elasticity.

In the case of pinned supports, we, according to the theory, considered the effective buckling length to be equal to the distance between the joints (with reducing factor $\mu = 1$, $\mu l = l$). Consequently, also $C = 1$. In the case of long columns, however, the values of critical stress, obtained in this way, did not correspond to the experimental values.

Good accordance between the experimental results and the results calculated according to Eq (3) was obtained in case of the reduction of effective buckling length. The buckling length correction was necessary in all the cases (Table 2).

Tab. 2 Values of μ *and C* recommended for specific end restrains according to the authors referred.

Material	***Pinned***				***Fixed***			
	MC₁		***MC₂***		***MC₁***		***MC₂***	
	μ	***C***	μ	***C***	μ	***C***		
Plywood	0.58	3	0.58	3	0.53	3.5	0.53	3.5
PB	0.58	3	0.58	3	0.53	3.5	0.53	3.5

As the result of higher C values, the limit slenderness value has been shifted higher, which caused a reduction of the long columns area. The works KÚDELA and SLANINKA (2002) KÚDELA and HOVORKOVÁ (2007) dealing with solid wood columns and with OSB columns also suggest than reduction of the buckling length in the case of pinned supports is necessary.

Considering the fact that heterogeneity of structure and properties along the specimen´s height and over its crosscut surface cannot be totally excluded either in case of "pure" test specimens, we expected more probable worse column stability. PINSKY (2000) suggests for pinned supports to treat the columns loaded centrically as columns loaded eccentrically and he also proposes a particular value of eccentricity. Experimental results showed that the stability of columns made of wood and wooden materials is better compared to the theoretic expectations.

The technical realisation of the end pinning has a very important influence on the effective length; this reduction of the effective length, however, cannot be explained through imperfect joints alone, as the *C* values were obtained different for different materials. Important role is to be assigned to the material itself, its toughness and deformability in compression parallel to the board plane, which is also influenced with the moisture content of the material.

In case of long columns with both ends fixed, the critical stress calculation was again carried out with the aid of Euler equation (3), considering, in accordance to the theory, a reducing length coefficient $\mu = 0.5$ ($C = 4$). Also in case of fixed ends, the effective length reduction was necessary (Table 2).

The need of this correction can be explained by the fact that in case of wood and wooden materials, it is not easy to manage perfect fixing of the column's ends. The fixed ends of columns loaded in buckling were simultaneously pressed perpendicular to the grain. This resulted in a partial release of the ends. In our case, this phenomenon was more manifested in plywood columns.

PINSKY (2000) recommends for columns with both ends fixed (without more detailed specification concerning the material) to provide calculations of critical stress with an effective length value of $0.65l$, and the corresponding value of $C = 2.37$. The work MONASH UNIVERSITY (1999), recommends using even an effective length of $0.7l$ ($C \cong 2$).

Having considered the area of short columns where $\sigma_{cr} = \sigma_{sl}$ and the area of intermediate columns defined with two points with coordinates (λ'_L, σ_{sl}) and (λ_L, σ_{pl}), the dependence of critical stress on slenderness ratio in area of intermediate columns can be described with the equation

$$\sigma_{cr} = \left(\sigma_{pl} - \sigma_s\right) \cdot \left(\frac{\lambda - \lambda'_L}{\lambda_L - \lambda'_L}\right)^2 + \sigma_s \,, \tag{4}$$

where σ_s is strength in compression parallel to grain, λ'_L is boundary slenderness value between the range of short and intermediate columns.

The critical stress values obtained experimentally and the values calculated with Eqs (3) and (4) for plywood and PB boards are in Figs. 3 and 4.

The results (Figs 3 and 4) show that the performance of plywood columns and PB columns was similar in quality. Nevertheless, there were differences in quantity. Better stability was observed in plywood. In case of long columns with high slenderness ratio (λ >250) the differences between the materials tested were less conspicuous.

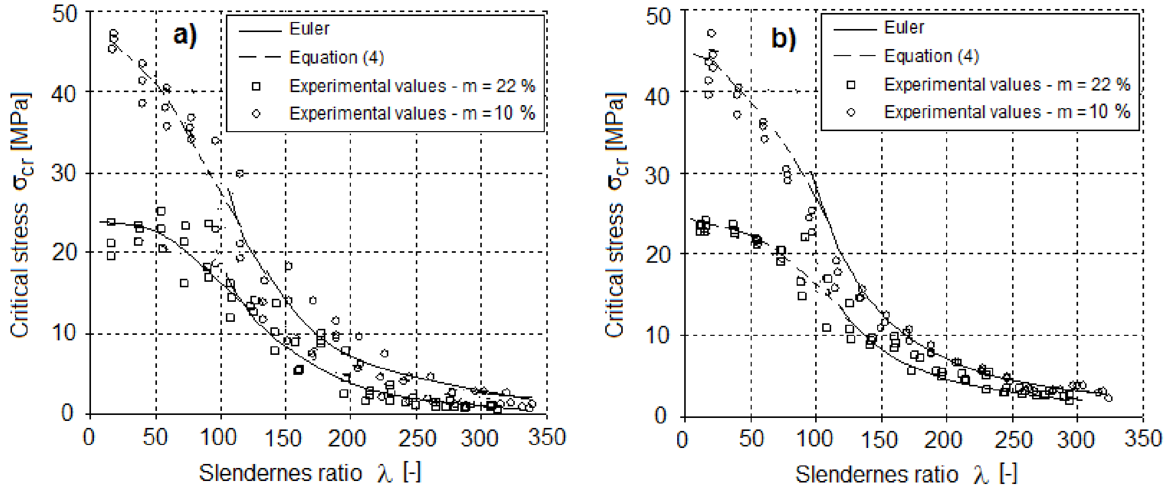


Fig. 3 Slenderness-ratio-related critical stress in plywood columns at two moisture content values a) pinned ends, b) fixed ends.

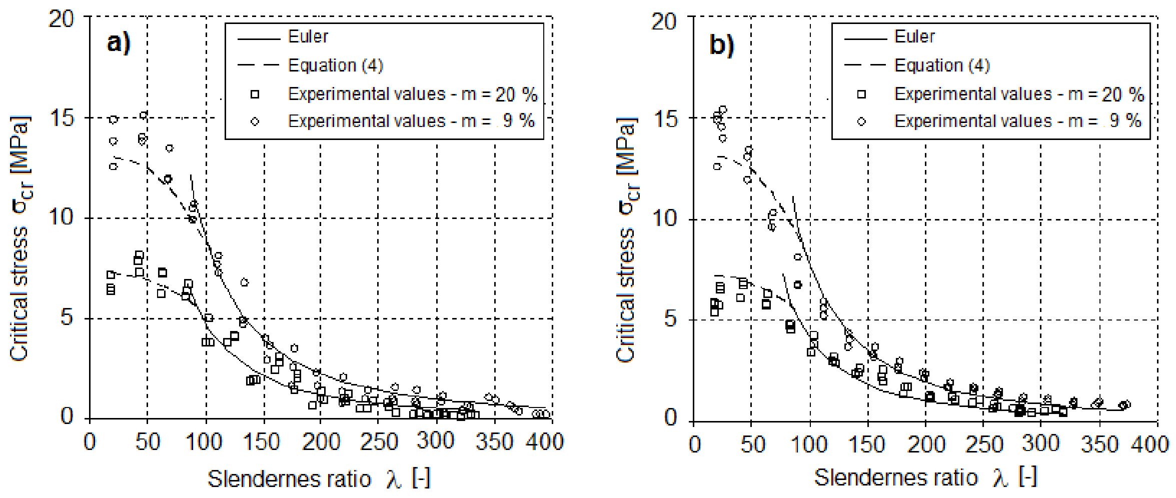


Fig. 4 Slenderness-ratio-related critical stress in PB columns at two moisture content values a) pinned ends, b) fixed ends.

The course of qualitative change in critical stress dependent on slenderness ratio was the same for low and high moisture contents. However, the critical stress values at the high moisture content were lower than the corresponding values at the low moisture content, over the whole buckling range. The change in moisture content from 10 % to 22 % was connected with a reduction of critical stress by about one half over the whole buckling range. For long columns with both ends pinned, the differences were somewhat smaller (40 %). In this case, the influence of moisture was partially masked by other factors, mostly by the material's heterogeneity.

The obtained results reveal that it is necessary to explore the dependence of critical stress on moisture content for all the areas – short, intermediate and long columns, to determine the dependence of critical stress on moisture content for all the buckling range and to propose correction moisture coefficients for conversion of the values of critical stress from moisture content m_1 to moisture content m_2.

CONCLUSION

Based on analysis of the experimental results, we can derive the following conclusions:

Moisture content exhibited an important influence on values of critical stress over the whole buckling range. The increase of moisture content from 10 to 22 % induced an average reduction in critical stress by 50 %.

Calculation of critical stress in area of long columns can be carried out with using the Euler equation. As technical realisation of the column ends fixing in practice mostly does not comply with the theoretical assumptions, it became evident that the correction of effective buckling length is necessary.

Based on sound physical background of the used equations and close correlation between the experimentally obtained and theoretical results we recommend to carry out calculation of critical stress in the area of intermediate columns with using Eq (4).

These conclusions are valid for dry as well as wet columns.

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