Preparation and Characterization of Cork Layered Composite Plywood Boards

Pavel Král,* Petr Klímek, Pawan Kumar Mishra, Peter Rademacher, and Rupert Wimmer

In the furniture and construction industries, there is increased demand for lightweight, high-performance, and low-maintenance materials with specific properties. Increased demand necessitates testing of new and composite materials to find a viable alternatives to classical materials. In this study, two different types of cork layered plywood composites (plywood board with a cork core (PLYW-K1), and plywood board with a cork core and cork face layers (PLYW-K2)) were prepared and tested for their basic mechanical properties as well as screw withdrawal resistance. The measured properties were compared with standard particleboard (PB) and plywood board (PLYW1) to determine the difference in properties and potential applications. The results presented include preparation parameters, mechanical properties, maximum withdrawal force, and withdrawal resistance. In addition, the effect of screw diameter and material density on withdrawal resistance was observed. Results indicate that cork-layered plywood possessed superior mechanical properties and withdrawal strength at a much lower density than particleboard. In comparison to classical plywood, the improved factors were a reduction in density and production cost.

Keywords: Withdrawal strength; Cork layered plywood boards; Particleboard; Plywood

*Contact information: Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 3, 613 00 Brno, Czech Republic; *Corresponding author: kral@mendelu.cz*

INTRODUCTION

Plywood was one of the first engineered wood products. It consists of wood plates that, when glued together, create a larger and more solid composite unit that is firmer and tougher than the individual parts. In the late 1970s and early 1980s, the principle of plywood gave rise to OSBs (oriented strand boards). These products allowed engineers to combine materials with different properties and origins into composites (Bao *et al*. 1996; Sharp and Suddarth 1991). Cork is a lightweight, elastic, and flexible natural material with excellent thermal, vibrational, and acoustic insulation properties (Gill 2009). Such a combination of properties enables cork to form part of various composites in its native and recycled forms (Lança *et al.* 2006; Gill and Silva 2004).

Combined plywood materials show, in addition to their static properties, various other characteristics, such as thermal and acoustic insulation. Through the combination of these two characteristics, a composite material of better properties than the individual materials is formed (Král and Hrázský 2006). This allows for the manufacturing of economical products with simple production technologies and high productivity. Combined plywood materials are not manufactured in such high volume as plywood for construction purposes (Hrázský and Král 2004).

Static holding capacity is usually established as the force in Newtons needed for fastener withdrawal or penetration into wood or wood-based material, or as the tension (resistance) that is allotted to a unit of area of the fastener contact (Matovič 1993). In 1987, Požgaj made the values of tension more accurate by considering the depth of screw penetration. On average, the force needed to withdraw a screw is about two times greater than the force needed to withdraw a nail with the same diameter and twice the length (Matovič 1993). The withdrawal resistance, being a specific quantity calculated from the withdrawal force and depth of screw penetration, should be treated as a material property (Šúriková 2001).

Screws in wood usually have a lower holding capacity in shear stress than nails or pins with the same nominal diameters. This is because the holding capacity of the threaded portion of the screw is lower than that of a full shank due to the smaller cross-section of the core (Koželouh 1998). Eckelman expressed empirical relationships for the calculation of the maximum withdrawal force from composite materials for screws (PB, MDF). The relationships take into account the screw diameter, the penetration depth, and wood density. For example, the withdrawal force for medium density fibreboard is 40% higher than that for particleboard (Eckelman 2003).

EXPERIMENTAL

Preparation of Composite Materials

Ten layer plywood board with beech and spruce veneers as a control sample (PLYW) was prepared with parameters same as PLYW-K1 but without a cork layer. Three layer particleboard 18 mm thick supplied by local producer KRONOSPAN, which meets requirements of EN 312 on type P2 (PB), was used as a second control sample. Plywood boards with a cork core (PLYW-K1) and plywood boards with a cork core and cork face layers (PLYW-K2) were produced in the arrangements shown in Figs. 1 and 2. The processing conditions were as follows: a pressure of 1,2 N·mm^{-2}, temperature of 110 to 120 °C, and a urea–formaldehyde adhesive “PREFERE 4170” with hardener “KORNOADD HL 100”.

The adhesive mixture was applied on veneers in the amount of 120 g·m^{-2}. To process the boards, a hydraulic laboratory press (60-ton pressure capacity) with a plate dimension of 700 × 700 mm was employed. All materials were processed according to standard EN 326 – 1 for sampling.

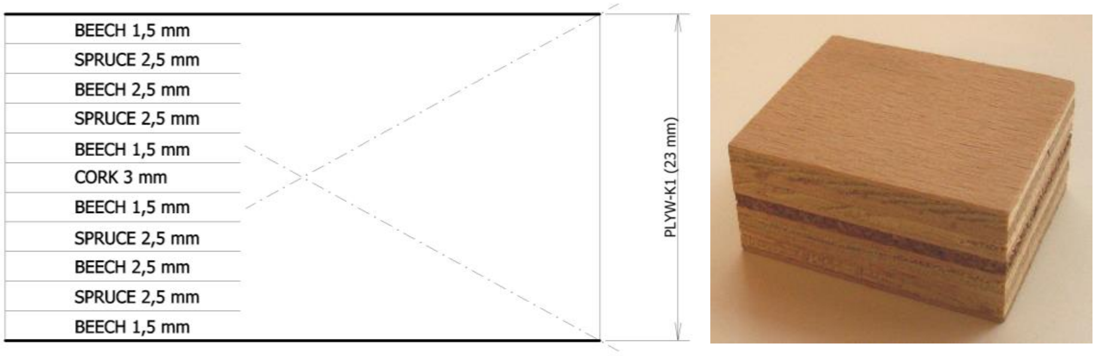

Fig. 1. Composition of plywood with cork core (PLYW-K1). The composition of the layers in the cross-section is shown.

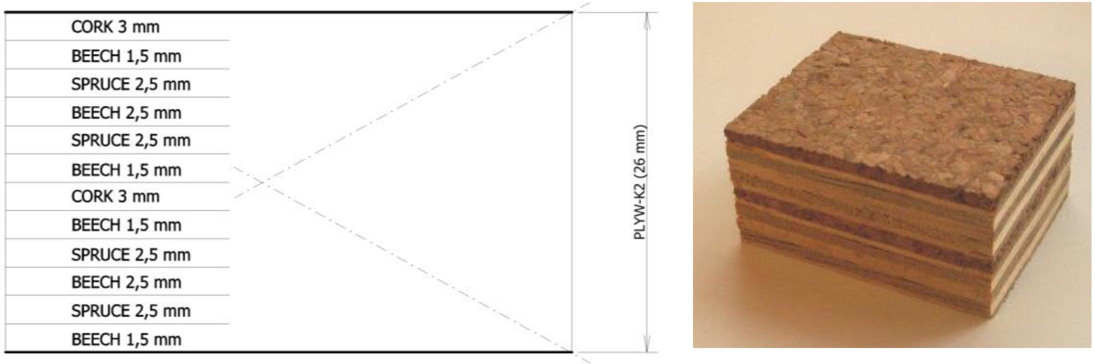

Fig. 2. Composition of plywood with cork core and surface layer of cork (PLYW-K2). The composition of the layers in the cross-section is shown.

Measurement of Mechanical Properties

All tests were performed with a ZWICK®Z050 universal testing machine, and data were processed using testXpert V11.02 software. A loading speed of 5 to 15 mm·min^{-1} was used. Data were recorded for each sample and then evaluated statistically. The following standards were utilized for measurements and sample processing.

- EN 326: 1 Boards of wood. Sampling, cutting, and inspection. Part 1: Sampling, cutting specimens and the formulation of test results
- EN 325: Determination of specimen dimensions
- EN 310: Determination of the modulus of bending elasticity and strength
- EN 322: Determination of moisture
- EN 323: Determination of density
- EN 314–2: Requirements for the quality of gluing plywood

Measurement of Withdrawal Resistance

Withdrawal resistance is affected by various factors, and in the present research the effects of board composition, density, and moisture content were considered. Although the material itself was the major factor, the standardized test contributed to variations as well. The withdrawal point location, either the face or edge of the sample, the type of fastener, board dimensions, *i.e.*, diameter and length, and depth of penetration were included in this research. The screws of SPAX®, 3,5x35 A2 BN 5209 SPAX – S, 4x35 A BN 5209 SPAX-S, and 5x 35 A2 BN 5209 SPAX-S were utilized in the test procedure as fasteners. Exactly 1,500 conditioned samples (20 ± 2 °C and 65 ± 5% relative humidity) with dimensions of 50×50 mm were tested according to the standard method based on EN 13446.

To calculate the screw withdrawal resistance, resistance expressed as the ratio of maximum withdrawal force and penetration depth was used. A constant screw penetration depth of 12 mm was employed. Therefore, the interpretation of the calculated resistance values of the particular materials was the same as in the case of the maximum withdrawal force. The maximum load was achieved, and withdrawal parameters were determined.

Statistical Evaluation

The measured data were analyzed using STATISTICA 10 software. First, an exploratory data analysis (EDA) was carried out. Based on these methods, the data were evaluated for their degree of symmetry and kurtosis, localized groupings of data, outliers, and consistence with the normal distribution. The Q–Q plot with the implemented Shapiro-Wilk test was also used to assess the normal distribution.

RESULTS AND DISCUSSION

The bending properties of PLYW-K1 and PLYW-K2 were found to be lower than those of PLYW1, but these samples performed better than PB samples. The modulus of elasticity (MOE) and modulus of rupture (MOR) of PLYW-K1 were found to be greater than those of PB by 48.57% and 131.04%, respectively but less than those of PLYW1 by 48.01% and 45.15%, respectively at a density that was 7.24% and 27.42% lesser then PB and PLYW1, correspondingly. For PLYW-K2, the MOR showed an increase of 106.31% and MOE showed a decrease of 38.67%, at a density 11.4% lesser compared to PB. In contrast MOR, MOE, and density were found to be 53.5%, 77.36%, and 30.74% smaller than PLYW1. The difference in behavior of PLYW1 and PLYW2 can be attributed to surface location and softness of cork layer and was found to be less than that of both PB and PLYW1. The density of cork layered plywood was significantly lower than that of commercial plywood board and particleboard (PB). Descriptive statistics are included in Table 1 and graphically compared in Figs. 3, 4, and 5.

Table 1. Bending Properties and Density

			MOR	MOE	DENSITY
PLYW- K1	**Arithmetic mean**	**N·mm^{-2}**	**46,07**[r]	**5191,3**	**592,12 kg·m^{-3}**
	Standard deviation	N·mm^{-2}	3,92	269,26	9,61 kg·m^{-3}
	Variation coefficient	%	8,51	5,19	1,62%
PLYW- K2	**Arithmetic mean**	**N·mm^{-2}**	**41,15**[r]	**2142,6**	**565 kg·m^{-3}**
	Standard deviation	N·mm^{-2}	2,4	230,46	9,8 kg·m^{-3}
	Variation coefficient	%	5,84	10,76	1,73%
PLYW1	**Arithmetic mean**	**N·mm^{-2}**	**88,63**	**9464,5**	**815,88 kg·m^{-3}**
	Standard deviation	N·mm^{-2}	9,9	411,05	10,97 kg·m^{-3}
	Variation coefficient	%	0,34	4,34	1.34%
PB	**Arithmetic mean**	**N·mm^{-2}**	**19,94**	**3494**	**638,22 kg·m^{-3}**
	Standard deviation	N·mm^{-2}	2,11	234,78	12,3 kg·m^{-3}
	Variation coefficient	%	3,16	5,99	1,21%

- $p < 0,01$

[r] Values having the same letter are not significantly different (Duncan test)

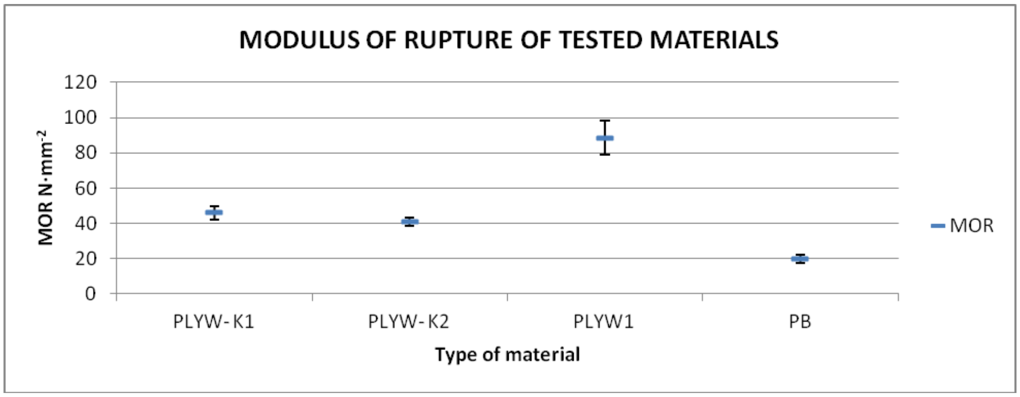

Fig. 3. MOR of tested materials

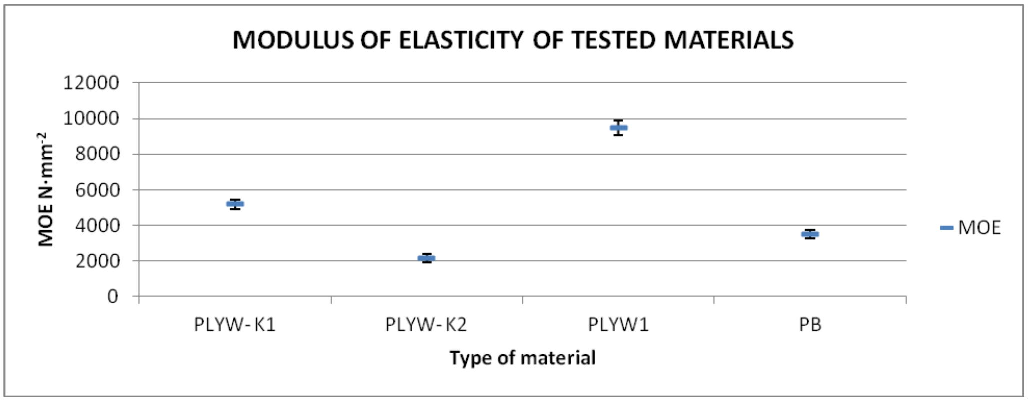

Fig. 4. MOE of tested materials

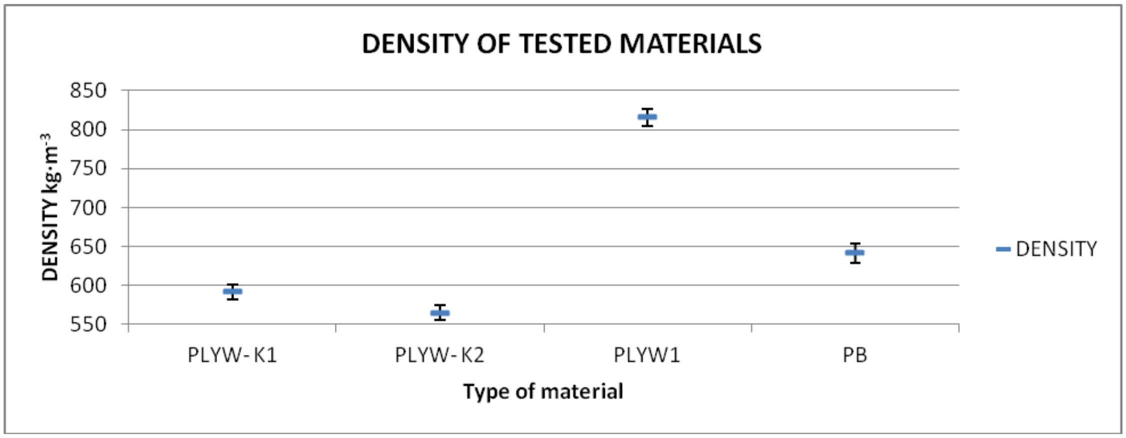

Fig. 5. Density of tested materials

Withdrawal resistance

The control sample PLYW1 showed the best performance, as expected. Nevertheless, the withdrawal resistances of PLYW-K1 and PLYW-K2 were better in the surface direction compared to that of PB. In the edge direction, a statistically insignificant difference was found due to a smaller screw diameter (4 × 35 *vs*. 3.5 × 35). Descriptive statistics are included in Table 3 and graphically compared in Figs. 6 and 7.

Table 3. Withdrawal Resistance for Tested Materials

			Surface			Edge		
			5 x 35	4 x 35	3.5 x 35	5 x 35	4 x 35	3.5 x 35
PB – L •	**Arithmetic mean**	**N·mm^{-2}**	**49,2**	**45,47**^{z}	**44,31**^{z}	**29,1**^{u}	**27,54**^{u}	**24,89**
	Standard deviation	N	5,13	3,95	4,12	3,85	3,97	2,92
	Variation coefficient	%	10,43	8,69	9,3	13,24	14,41	11,74
PLYW- K1 •	**Arithmetic mean**	**N·mm^{-2}**	**90,14**	**81,2**^{w}	**80,54**^{w}	**46,94**^{t}	**31,73**^{s}	**17,98**^{r}
	Standard deviation	N	10,91	6,54	5,11	5,53	5,2	4,91
	Variation coefficient	%	12,1	8,5	6,35	11,78	15,83	27,31
PLYW- K2 •	**Arithmetic mean**	**N·mm^{-2}**	**60,5**	**57.14**^{v}	**56.26**^{v}	**46.94**^{t}	**31.73**^{s}	**17.98**^{r}
	Standard deviation	N	7,29	5,52	5,31	5,53	5,2	4,91
	Variation coefficient	%	12,4	9,66	9,44	11,78	15,83	27,31
PLYW1 •	**Arithmetic mean**	**N·mm^{-2}**	**141,92**	**128,95**^{x}	**127,81**^{x}	**99,28**	**116,39**^{Y}	**113,7**^{Y}
	Standard deviation	N	8,29	6,94	8,29	31,75	6,61	13,63
	Variation coefficient	%	5,58	5,38	6,49	31,98	5,68	11,99

• p < 0,01

$^{r; s; t; u; v; w; x; y; z}$ Values having the same letter are not significantly different (Duncan test)

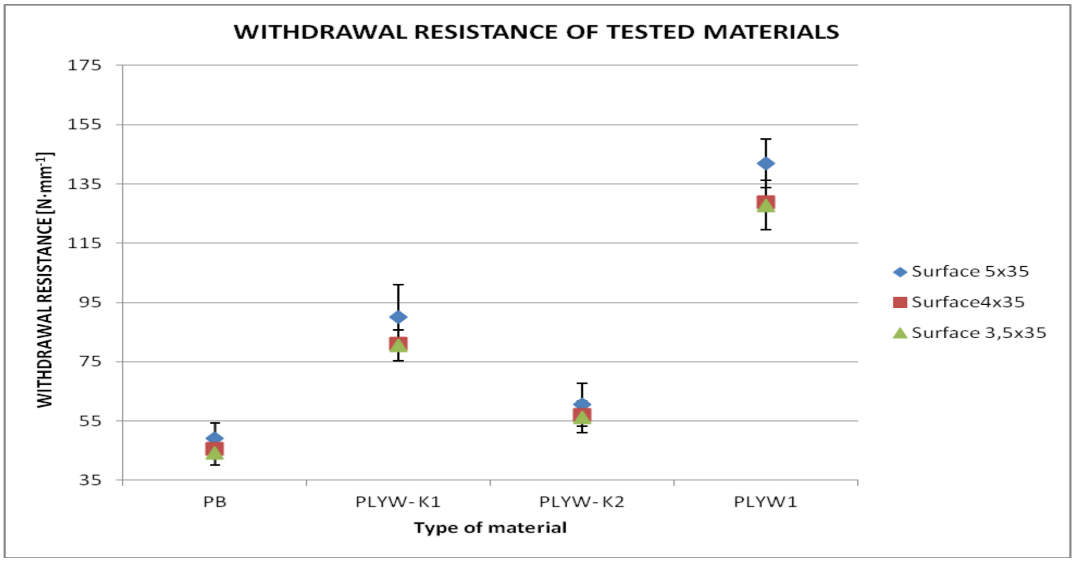

Fig. 6. Withdrawal resistance for tested materials in the surface direction

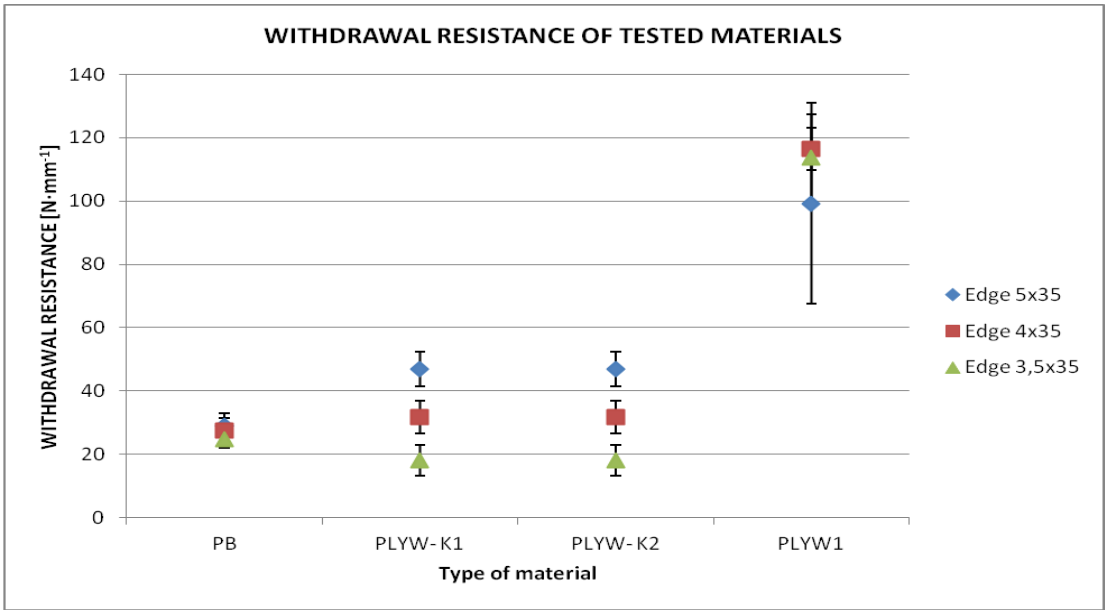

Fig. 7. Withdrawal resistance for tested materials in the edge direction

The density, which is considered to be a crucial property of building materials, was successfully reduced compared to that of particleboard, which is widely utilized in the wood–construction industry, by including cork layers in the plywood. These results provide a strong argument for the future use of these materials.

Although the density is a key criterion for materials use, other properties may be equally important. MOE, MOR, and withdrawal resistance were each assessed. The control sample (PLYW1) was found to possess significantly higher bending properties than the new materials, but the major objective was to optimize density and obtain properties that could compete with widely used particleboard.

The bending properties of PLYW-K1 with a cork core provided better bending performance, despite the presence of the soft material in the central layer. The MOE of PLYW- K2 was found to be lower than that of PB, which can be attributed to the face layer made of cork, which is very soft and flexible and shows more pronounced deformation during bending. This is also confimed by the significantly higher MOR compared to that of PB.

The highest resistance to screw withdrawal was found in the control sample of plywood. PLYW-K1 and PLYW-K2 presented relatively low resistance to screw withdrawal compared to plywood, but they were significantly higher than the results for PB. Nevertheless, a difference was found in the withdrawal test, at the edge and center of the board. A statistically significant difference for screws of 3.5 x 35 mm and 4 x 35 mm was reported for PLYW-K1 and PLYW-K2, respectively. Withdrawal resistance was found to be lower for screws with lower diameters. This trend was followed for both edge and central locations. No locational effect on withdrawal resistance was observed in PB, but PLYW1 showed this effect. Screw diameter presented a negligible effect in PB and PLYW1.

As expected, according to total density, PB (642 kg/m^3) achieved significantly lower resistance than the lighter newly established materials. On the other hand, the PLYW-K2 (571 kg/m^3) had a 30% reduced screwing capacity compared to PLYW-K1 (594 kg/m^3), despite the fact that the density was different by only 23 kg/m^3. Although the face layer made of cork could present some disadvantages, material attributes such as softness or texture could easily match the needs of the market.

CONCLUSION

The objective of this research was to propose and evaluate light-weight alternatives to particle boards using modified plywood.

1. PLWK1 and PLWK2 were found to have significantly lower densities than plywood and much lower than particle boards.
2. The MOR and MOE of both the materials were significantly higher than particle boards and lower then plywood boards.
3. Withdrawal resistance from the surface was found to be higher than particle boards and lower then plywood for both materials. However, on the edge, withdrawal resistance was found to be lower because of the cork layer.
4. Both of the new materials had a withdrawal strength that was affected by screw diameter, which requires more investigation.

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REFERENCES CITED

Bao, Z., Eckelman, C., and Gibson, H. (1996). “Fatigue strength and allowable design stresses for some wood composites used in furniture,” *Holz Roh Werkst.* 54(6), 377-382.
ČSN EN 13446. (2013). “Wooden panels. Determination of the resistance to the withdrawal of connecting means,” Czech Standardization Institute.
ČSN EN 1382. (2000). “Wooden constructions. Experimental methods. Bearing resistance to the withdrawal of connecting means,” Czech Standardization Institute.
Eckelman, C. A. (2003). *Textbook of Product Engineering and Strength Design of Furniture,* Purdue University, West Lafayette, IN.
Gil, L. (2009). “Cork composites: A review,” *Materials* 2, 776-789.
Gil, L., and Silva, P. (2004). “New multifunctional composites of Cork/TetraPak® residues,” in: *Materials Congress 2004*, London, UK.
Hrázský, J., and Král, P., (2004). “Analysis of properties of boards for concrete formwork,” *J. Forest. Sci*. 50(8), 382-398.
Koželouh, B. (1998). *Wooden Constructions According to Eurocode 5 - Step 1: Proposing and Construction Materials*, KODR, Zlín.

Král, P., and Hrázský, J. (2006). "Effects of different pressing conditions on properties of spruce plywoods," *J. Forest. Sci.* 52(6), 285-292.
Lança, M. C., Neagu, E. R., Silva, P., Gil, L., and Marat-Mendes, J. (2006). "Study of electrical properties of natural cork and two derivative products," *Mater. Sci. Forum* 514-516, 940-944.
Matovič, A. (1993). *Physical and Mechanical Properties of Wood and Wood-based Materials*, VŠZ, Brno.
Požgaj, A. (1987). *Methods of Determining the Mechanical Properties of Wood and Wood Based Composite Materials*, VŠLD, Zvolen.
Sharp, D. J., and Suddarth, S. K. (1991). "Volumetric effects in structural composite lumber," in: *Proceedings, 1991 International Timber Engineering Conference* 3, 427-437.
Šúriková, A. (2001). "Stress analysis in screw joint," *Zvolen: TU* 42, 29-37.
EN 326. (1994). "Wood-based panels – Sampling, cutting and inspection"
EN 325. (2012). "Wood-based panels – Determination of dimensions of test piece"
EN 310. (1993). "Wood-based panels: Determination of modulus of elasticity in bending and of bending strength"
EN 322. (1993). "Wood-based panels – Determination of moisture content"
EN 323. (1993). "Wood-based panels – Determination of density"
EN 314-2. (2008). "Plywood – Bond Quality – Requirements"

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