COMPARATIVE STUDY ON THE MECHANICAL PERFORMANCE OF BEECH AND ASH LAMINATED PANELS

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ABSTRACT

This paper presents a comparative study on the mechanical performance of beech and ash wood laminated panels. Within the experimental study the bending strength, bending modulus of elasticity and the bonding characteristics to gluing (bonding quality) were analyzed. The experimental results emphasized the influence of the type of wood, the panel thickness, the effect on the bending strength, respectively on the gluing quality of the direction of the wood lamellas in relation with the mechanical load (direction of cutting specimens). It can be said that the use of hardwood meets the needs and demands of the construction area, but it’s necessary a careful analysis of the requests that occur mainly at the site, thus an optimal direction of the wooden glued lamellas can be chosen. Laminated wood panels are a product with real physical and mechanical qualities, which can be successfully used to obtain construction elements that are bringing benefits to environmental quality of living areas.

Keywords: laminated wood panels; physico-mechanical properties

REZUMAT

Această lucrare prezintă un studiu comparativ privind rezistențele mecanice ale panourilor din lemn încleiat de fag şi frasin. În cadrul cercetărilor experimentale au fost analizate: rezistența la încovoiere, modulul de elasticitate la încovoiere şi caracteristicile de aderență la încleiere (calitatea încleierii). Rezultatele experimentale au pus în evidență influența materialului lemnos, grosimii panoului, direcției de poziționare a lamelelor de lemn in raport cu acțiunea solicitării mecanice (direcția de debitare a epruvetelor) asupra rezistentei la încovoiere, dar şi asupra calității încleierii. Se poate spune că utilizarea lemnului de foioase corespunde necesităților şi exigentelor din construcții, dar este necesară o analiză atentă a solicitărilor care apar preponderent în locul punerii în operă, astfel încât să fie aleasă o poziționare optimă a direcției lamelelor de lemn încleiate. Panourile din lemn încleiat sunt un produs cu reale calități fizico-mecanice, putând fi utilizate cu succes pentru realizarea unor elemente de construcții, aducând totodată beneficii privind calitatea mediului din spatiile de locuit.

Cuvinte cheie: panouri din lemn încleiat, proprietăți fizico-mecanice

1. INTRODUCTION

The pronounced increasing tendency regarding the interest on the use of wood in construction area has led to the development of research activities on the physical and mechanical characteristics of different types of wood and the identification and conception of finished products and their manufacturing technologies that will lead to improvements of the mechanical properties. The aim of this research was to identify technical solutions to ensure the increase of the mechanical strength but also to find solutions to ensure exploitation of the species commonly found in Romanian forests and those that can be grown easily and have a rapid increase [6, 22].

Romania has a tradition in wood processing, providing a rich resource forest. In the early 2000s about 26% of the total area of the country was covered by forests [22]. The wood species that are found commonly in the country are mainly beech (about 30%), resinous (about 30%) and oak (about 19%)

[21]. During the last years, there has been a marked increase in the volume of harvested timber: coniferous species by 43% to 28%, beech and oak by 9% [22].

In the early 90's, besides beams (known for over 100 years), the laminated wood panels have become increasingly researched and used [9, 11].

Panel structures use laminated wood strips of the same species or different species strengthened within the structure using adhesives, to obtain the following advantages [6]:

● the effective use of various wood species;
● the exploitation of low quality wood by combining it with good quality wood (to improve its characteristics);
● the development of structural elements with different sections;
● decreasing of the swelling – shrinkage phenomenon of wood, after humidity variations;
● the development of various building structures in terms of forms, aesthetic and architectural aspects.

The resinous wood is used more often as raw material. The use of various hardwoods has highlighted some areas of concern due to the high density of this type of wood and his gluing difficulties [2, 11, 12, 15, 16]. Krackler et al [10] have investigated the possibility of elimination or reduction of these disadvantages and promote the use of hardwood in the construction area.

Wood has the quality to absorb excess moisture and CO_2 from the air, providing a pleasant climate in living areas. In Switzerland, between 18% and 20% of the new buildings are made of wood and "Minergie" houses (low energy consumption) reaches 40% to 50% [11]. The major disadvantage is the economic aspect: the cost of construction of wood-based materials is higher than for those made of concrete or stone. According to the Winter journal [20], 1m^3 of timber building costs approximately 200 Euro compared to 1m^3 of concrete, costing approx. 50 Euro. Another disadvantage that can't be neglected is the depletion of current forest and the long period needed for its recovery.

According to the research started in the early 1990s by a group of researchers from the Technical University of Gratz, ETH Zurich and IHD Dresden [4, 5, 7, 8, 9, 11, 17], but also according to other bibliographic references [2, 3, 5, 12-14, 16], it was proven that the main factors influencing the physico-mechanical properties of laminated wood panels are:

- the material properties / of wooden materials that are part from the composition of panels (modulus of elasticity in bending, torsion modulus, mechanical strength);
- panel structure (layer thickness, adhesive);

Wetzig, Hass and Niemz [19] have investigated the properties of layered panels of solid beech, ash, spruce and combinations of species. Their main objective was to reduce the tensions caused by humidity variations by changing the type and thickness of the adhesive. Research results have shown the influence of the elasticity and thickness of the adhesive on the physico-mechanical properties of the glued panels. The structural adhesives most used until now are phenol-resorcinol adhesives (PR), melamine-urea-formaldehyde (MUF), Polyurethane (PUR) and epoxy (EPX) [1, 16, 18].

This paper presents and analyses the results obtained for glued panels made of beech and ash, with thicknesses of 35 mm and 42 mm, respectively. The tests regarding the bending strength, bending modulus of elasticity and adhesion characteristics to gluing (bonding quality) of the laminated panels were carried out at the National Institute for Research and Development In Construction, Urban Planning and Sustainable Spatial Development URBAN-INCERC, Cluj-Napoca Branch.

2. MATERIALS. THE METHOD FOR TESTING

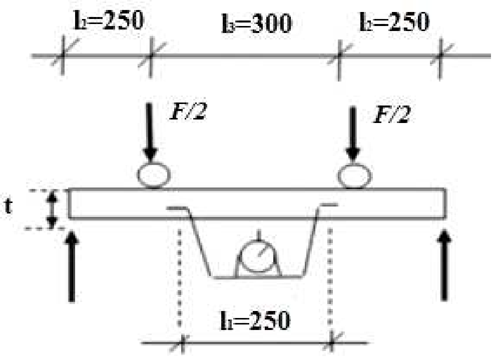
Tests were performed on a total of 26 sets of specimens made of beech or ash, which were produced and commercialized in Romania during a three-year period (2012-

2014). The presented results are average values for each type of laminated wood panel, depending on wood species and thickness. Production technology and type of gluing adhesive of the panels were the same. According to EN 204 [25], D3 group, an adhesive based on polyvinyl acetate was used for gluing. The individual values did not deviate with more than 10% from the average values.

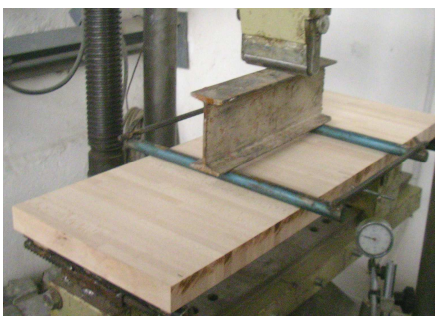
2.1. Determination of bending strength. Determination of bending modulus of elasticity

For the determination of bending strength and bending modulus of elasticity specimens with rectangular cross section were used. The beech and ash panels had a width of 300 mm, 1100 mm length and thicknesses of 32 mm and 42 mm, respectively. According to SR EN 789 [23], the panels were debited in the longitudinal and transverse direction.

The specimens were conditioned to constant mass in a chamber with relative humidity of 65% ± 5% and temperature 20 ºC ± 2 ºC, according to SR EN 789.



a) Bending test setup



b) Images taken during experimental test

Figure 1. Determination of bending strength. Determination of modulus of elasticity in bending

Figure 1a shows the method used for applying the load. The distance between the loads application points and the supports was 250 mm.

The loading speed was constant and chosen so that the maximum load is reached in 300 ± 120 seconds.

The bending strength and the bending moment were calculated for each specimen (cut longitudinally or transversely), based on equations (1) and (2) [23]:

Bending strength:

$$f_m = \frac{F_{\max} \cdot l_2}{2W} \quad (\mathrm{N/mm^2}) \qquad (1)$$

where:

F_{max} – maximum load, N;

l_2 – distance between an inner load point and the nearest support, mm;

W – section modulus, mm^3;

Resisting moment:

$$M_{\max} = \frac{F_{\max} \cdot l_2}{2} \quad (\mathrm{N\ x\ mm}) \qquad (2)$$

where:

F_{max} – maximum load, N;

l_2 – distance between an inner load point and the nearest support, mm;

W – section modulus, mm^3.

The deflection was measured midway between two points on the axis of the specimen located in the zone of uniform moment (l_1). The load-deflection diagram was obtained using the data from the graph between 0,1F_{max} and 0,4F_{max}, from a linear regression analysis (Fig. 2).

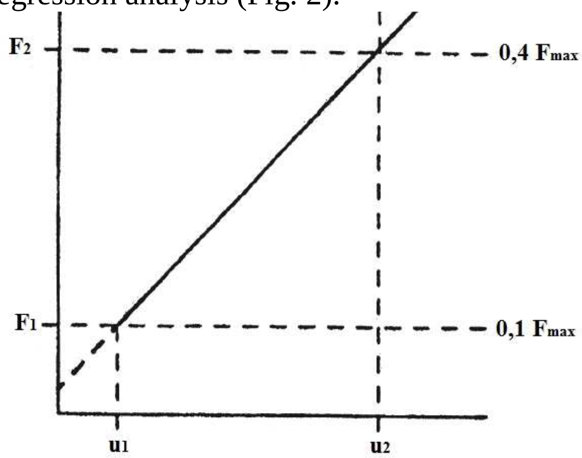


Figure 2. Load-deflection graph with the range of elastic deformation

The bending modulus of elasticity and the bending stiffness of the specimens were determined by applying a load at two points on the specimen supported on the two supports, using the slope of the straight part of load-deformation curve and equations (3) and (4) :

Bending modulus of elasticity:

$$E_m = \frac{(F_2 - F_1) \cdot l_1^2 \cdot l_2}{16(u_2 - u_1)I} \qquad (3)$$

Bending stiffness:

$$E_m I = \frac{(F_2 - F_1) \cdot l_1^2 \cdot l_2}{16(u_2 - u_1)} \qquad (4)$$

where: F_2 - F_1 – load increment between $0{,}1F_{max}$ and $0{,}4F_{max}$, N;

u_2-u_1 - the increment of deflection corresponding to F_2 - F_1, using the linear regression line;

l_1 =250 mm;

I – second moment of area, mm^4.

2.2. Determination of bonding quality

The bonding quality of beech or ash wood panels was determined according to SR EN 13354 [24], by strained to failure by a compressive shear force. When cutting the sample strips the cutting plan should provide test pieces from both near the edge of the board and from the centre. The specimens had the shape and dimensions shown in Figure 3.

The equipment used for the test was a compression testing machine fitted with a shearing tool, as shown in Figure 4.

After determining the length and width of the shear area, the specimens were placed in the shearing tool and a constant rate of load was applied, so that failure occurs within approximately (60±30) s. For each tested specimen was determined the maximum load at failure was recorded. The tests were carried out on specimens in dry conditions.

The shear strength of each test piece is calculated using equation (5).

$$f_v = \frac{F}{l \cdot b} \ (\text{N/mm}^2) \qquad (5)$$

where: F – the maximum load of the test piece, N;

l – length of the shear area, mm;

b – width of the shear area, mm.

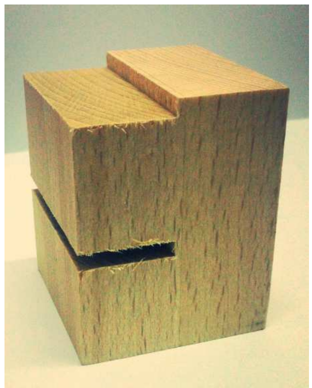


Figure 3. Specimen taken from laminated wood panel

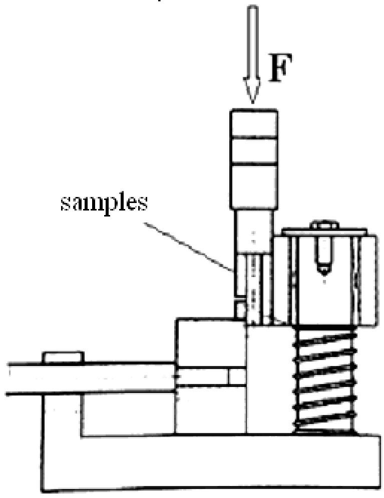


Figure 4. Adjustable shearing tool with test piece in position (side view) [24]

3. MATERIALS. TESTING METHOD

3.1. Determination of bending strength. Determination of bending modulus of elasticity

As it can be seen in Figure 5 the type of wood, the thickness of the laminated panels and direction of debiting are influencing the bending strength of the specimens. In the case of beech panels, with the greatest thickness of the boards, the bending strength on the longitudinal direction was with 27% smaller then the bending strenght obtaind on transversal direction. With reference to the transverse direction, the different thicknesses of the panels did not influence significantly the bending strength. For the same thickness of the multi-layer wood panel (42 mm), it can be observed that the essence of wood is influencing the bending strength on the longitudinal direction, the beech panel having a bending strength with 19% less than the ash panel. The bending strength is not influeced by the debiting on transverse direction.

In general, it was observed that the longitudinal direction (due to the positioning of fibers) the wood essence is influencing the bending strength. On the transverse direction, because there is a cutting wood fiber (resulting more clusters of shorter fibers, respectively many glued surfaces) the influence on the type of wood on the bending strength is negligible.

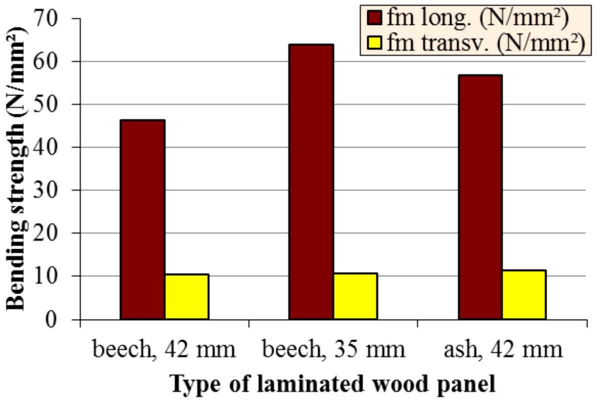


Figure 5. Bending strength of the specimens debited in the longitudinal and transverse direction

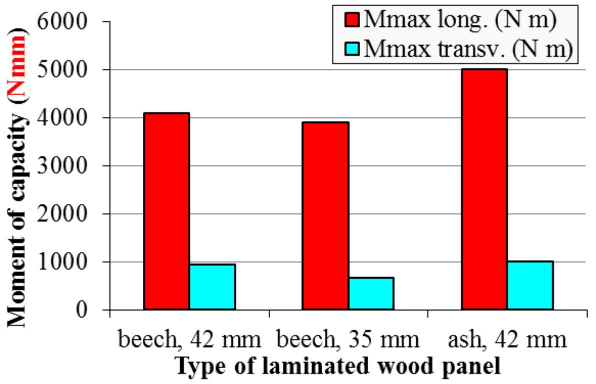


Figure 6. Resisting moment of the specimens debited in the longitudinal and transverse direction

The resisting moment of the specimens (Figure 6), is influenced more by wood type (beech 42 mm compared to ash 42 mm) than by the thickness variation of the wood panels of the same essence (beech 42 mm versus 35 mm).

The debiting direction of test specimens influences significantly the resisting moment, the specimens debited longitudinally showing a resisting moment 3,33 times higher for the beech with 42 mm thickness, 5,05 times higher for the beech with 35 mm thickness and 3,94 times higher for the ash panel with 42 mm thickness, as compared with their correspondents debited on transverse direction. At the same thickness of the panel, the resisting moment of the ash specimens debited in the longitudinal direction is approximately 22,5% higher that of the beech specimens. The recorded values for the specimens debited in transverse direction are not significantly different for the analyzed situation, which leads to the conclusion that the resisting moment is also influenced by the wood fiber length and the number of glued areas.

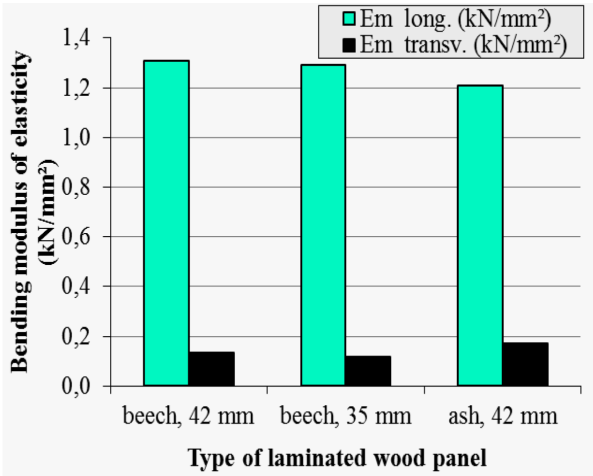


Figure 7. Bending modulus of elasticity of the specimens debited in the longitudinal and transverse direction

Regarding the bending modulus of elasticity, the influence of the type of wood and of the debiting direction on the specimens is more obvious (Figure 7). The biggest value for the bending modulus of elasticity is recorded on the beech wood specimens, therefore they allow deformation greater than ash.

The bending modulus of elasticity is not significantly influenced by the thickness of the panel, but it decreases with approximately 90% for the specimens debited in transverse direction, compared to the corresponding values of the specimens debited in the longitudinal direction. A decrease with 85% of the bending modulus of elasticity of the ash specimens debited in transverse direction is remarked compared to the specimens debited in the longitudinal direction.

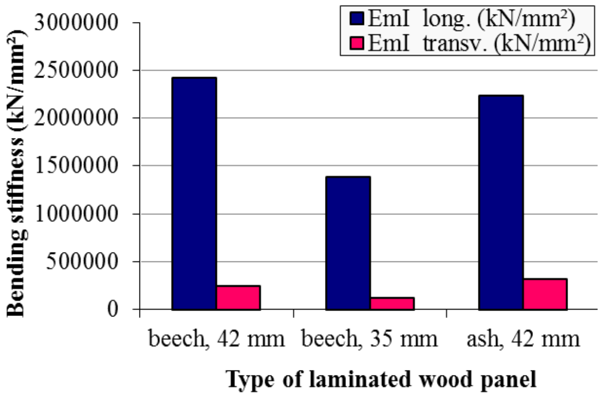


Figure 8. Bending stiffness of the specimens debited in the longitudinal and transverse direction

The bending stiffness (Figure 8) is mainly influenced by the direction of debiting of the specimens, the values of the bending stiffness of the specimens debited in transverse direction are smaller than the corresponding specimens debited in the longitudinal direction, regardless the wood type.

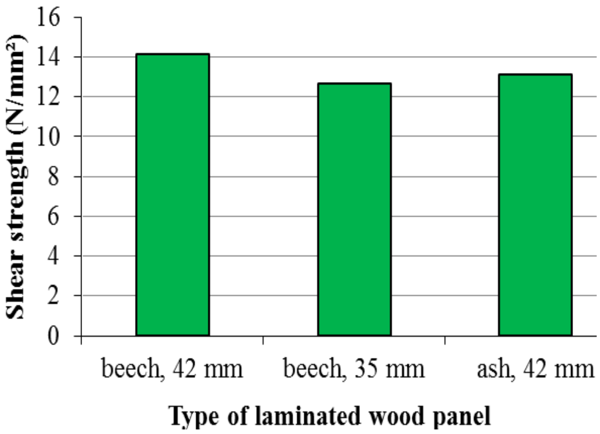
For the same type of wood (beech), the bending stiffness decreases with the reduction of the thickness of specimens.

For the same thickness of the specimens (42 mm), it is observed that the specimens of beech wood are showing a higher value for bending stiffness on the longitudinal direction and a smaller value on the transverse direction, compared to the specimens of ash wood.

3.2. Determination of the bonding quality

The bonding quality of wood panels was verified by shearing the glued section, for every type of wood. Considering that in all cases the failure occurred by shear and not in the glued surface, a comparative analysis can be done on the shear strength of the wood. Also it can be concluded that the adhesive used was appropriate for gluing wooden panels because failure has not occurred in wood-adhesive interface. The shear strength is influenced by the type of wood, but as well by the thickness of the panel (Figure 9), as follows:

- in the case of beech wood there is a decrease in the shear strength, with decreasing the thickness of the panel, respectively with reducing contact surface. Beech specimens of 35 mm presented the lowest values of shear strength.
- for the same thickness of the laminated wood panels, 42 mm respectively, values with about 7% higher were obtained for beech wood panels compared with the ash panels, from which results a similar behavior in shear, of the two types of wood panels in shear.



Note: the failure hasn't occured through the glued surface

Figure 9. Shear strength for laminated wood specimens

4. CONCLUSIONS

Based on experimental research the following were established:

- Regardless of the studied mechanical properties, for the same type of wood, it was found that their properties are influenced by the thickness of the panel, compared to the mechanical properties of a homogeneous material (to which these properties are preserved regardless the characteristics of the section). In the case of wood, due to the inhomogeneity of the fiber (layout, length, knots etc.) this constant of the mechanical properties is not preserved for the same wood type, conclusion that is in accordance with research started in the '90s and continued to the present [4, 9-14, 19-23]. For this reason, it is important to verify the mechanical characteristics of interest of the wood material for those uses.

- The bending strength and the resisting moment of the laminated wood panels are influenced by the direction of debiting of the specimens; the obtained values are significantly higher in the longitudinal direction, along the fiber; when the specimens are debited in transverse direction there is a cutting of the wood fiber, as there are actually many and shorter clusters and more glued surfaces, the bending strength is lower;
- The bending modulus of elasticity and bending stiffness are also influenced by the direction of specimens debiting and by the elastic properties of wood type and, to a lesser extent, by the panel thickness;
- From the analyzed values it results that for beech and ash, the panel thickness and the type of wood doesn't influence significantly the shear strength.

Regardless of the used type of wood, a careful analysis of the loads that occur is required, mainly depending on destination, so that the optimal position of the fiber direction and the appropriate thickness can be chosen.

REFERENCES

1. *Ballerini A., Despres A., Pizzi A., Non-toxic, zero emission tannin-glyoxal adhesives for wood panels, Holz als Roh- und Werkstoff, Volume 63, Issue 6, pp 477-478, December 2005*
2. *Blass H. J., Fellmoser P., Design of solid wood panels with cross layers, 8th World Conference on Timber Engineering, 2004 - ewpa.com*
3. *Dai C., Yu Ch. , Jin J., Theoretical modeling of bonding characteristic and performance of wood composites. Part IV. Internal bond strenght, Wood and Fiber Science, Society of Wood Science & Technology, ISSN 0735-6161, Vol. 40, No. 2, pp. 146-160, april 2008*
4. *Gereke T., Moisture - induced stresses in cross laminated wood panels, Dissertation, ETH Zürich, 2009*
5. *Gereke T., Schnider T., Hurst A., Niemz P., Identification of moisture - induced stresses in cross -laminated wood panels from beech wood (Fagus sylvatica L.), Wood Sci. Technol., 43:301–315, 2009*
6. *Giurgiu M., Cismaru I., Studiu comparativ privind comportamentul la solicitări mecanice al grinzilor din lamele încleiate din lemn de molid, pin si duglas, PRO LIGNO Vol. 7 N 3 2011, online ISSN 2069-7430, pp 18-28.*
7. *Gülzow A., Zerstörungsfreie Bestimmung der Biegesteifigkeiten von Brettsperrholz, Dissertation, ETH Zürich, 2008*
8. *Gülzow A., Gsell D., Steiger R., Non-destructive evaluation of elastic parameters of square-shaped cross-laminated solid wood panels, built up symmetrically with 3 layers, Holz Roh Werkst, 66:19-37, 2008*
9. *Joscak M., Sonderegger W., Niemz P., Krus M., Lengsfeld K., Grosskinsky Th., Holm A., Vergleichende Untersuchungen zum Feuchte - und Wärmeverhalten in unterschiedlichen Wandelelementen, Reihe Wissenschaft. Band 27, Fraunhofer IRB Verlag 2011*
10. *Krackler V, Keunecke D, Niemz P., Verarbeitung und Einsatzmöglichkeiten von Laubholz und Laubholzresten, ETH Zürich, Eigenverlag, 2010*
11. *Niemz P., Sonderegger W., Plăcile stratificate din lemn masiv - Proprietăłi si utilizarea în construcłii: o sinteză din experienła cercetătorilor elvełieni, PRO LIGNO Vol. 9 N 1 2013, online ISSN 2069-7430, pp 3-21*
12. *Park H.-M., Fushitani M., Effects of component ratio of the face and core laminae on static bending strength performance of three-ply cross-laminated wood panels made with sugi (cryptomeria japonica), Wood and Fiber Science, 38(2), pp. 278 – 291, 2006*
13. *Popovski M., Schneider J., Schweinsteiger M., Lateral load resistance of cross-laminated wood panels, Wold Conference on Timber Engineering, 2010*
14. *Resch L., Despres A., Pizzi A., Bocquet J. F., Leban J.-M., Welding-through doweling of wood panels, Holz als Roh- und Werkstoff, Volume 64, Issue 5, pp 423-425, October 2006*
15. *Schmidt M., Glos P., Wegener G., Verklebung von Buchenholz für tragende Holzbauteile, Eur. J Wood Wood Prod, 68:43-47, 2010*
16. *Steiger R., Gülzow A., Czaderski C., Howald M., Niemz P., Comparison of bending stiffness of cross-laminated solid timber derived by modal analysis of full panels and by bending tests of strip-shaped specimens, European Journal of Wood and Wood Products, 70(1-3), pp. 141-153, 2012*
17. *Tobisch S., Methoden zur Beeinflussung ausgewählter Eigenschaften von dreilagigen Massivholzplatten aus Nadelholz. Dissertation, Universität Hamburg, 2006*
18. *Zeleniuc O., Varodi A., Adezivi pe baza de rasină furanică pentru lemn lamelat pentru construcłii, PRO LIGNO Vol. 9 No. 2, online ISSN 2069-7430, pp. 39-49, 2013*

19. *Wetzig M., Hass Ph., Hänsel A., Niemz P., Untersuchungen zur Verklebung dreischichtiger Massivholzplatten unter Verwendung von Laubholz. Bautechnik, Bautechnik 88, Heft 10:689-693, 2011*
20. *Winter S., Präzise, schneller und sicherer. Interview mit Professor Wolfgang Winter über den Wiederaufbau im Erdbebengebiet von L` Aquila, Holzforschung Austria 7:12-13, 2009*
21. *Raport privind Resursele de lemn şi potențialul pieței din România, Asociația Forestierilor din România (ASFOR), www.asociatiaforestierilor.ro*
22. *Raport privind starea economică şi socială a sectorului de prelucrare a lemnului şi a mobilei, Federatia Sindicatelor Libere din Industria Lemnului Romania (FSLIL), PROJECT INNO Trans 2007 – 2008, Bucuresti, 17-18 martie 2008*
23. *SR EN 789:2004 Timber structures - Test methods - Determination of mechanical properties of wood based panels*
24. *SR EN 13354:2010 Solid wood panels (SWP) - Bonding quality - Test method*
25. *EN 204:2002 Classification of thermoplastic wood adhesives for non-structural applications*