Proceedings of PACAM XI
11th Pan-American Congress of Applied Mechanics
January 04-08, 2010, Foz do Iguaçu, PR, Brazil

MECHANICAL CHARACTERISTICS OF CHEMICALLY DEGRADED SURFACE LAYERS OF WOOD

Jiri Frankl, frankl@itam.cas.cz
Institute of Theoretical and Applied Mechanics, Academy of Sciences of the Czech Republic, v. v. i.

Michal Kloiber, kloiber@kloiber.cz
Mendel University of Agriculture and Forestry in Brno, Faculty of Forestry and Wood Technology, Department of Wood Science

Milos Dradacky, drdacky@itam.cas.cz
Institute of Theoretical and Applied Mechanics, Academy of Sciences of the Czech Republic, v. v. i.

Jan Tippner
Mendel University of Agriculture and Forestry in Brno, Faculty of Forestry and Wood Technology, Department of Wood Science

Jan Bryscejn, bryscejn@itam.cas.cz
Institute of Theoretical and Applied Mechanics, Academy of Sciences of the Czech Republic, v. v. i.

Abstract. *The aim of this research was to find out whether the effect of chemical corrosion changes mechanical characteristics of surface layers of wooden construction elements. Degradation of the surface layers of wood was caused by chemical reactions of the basic substances of wood mass with compounds contained in antifire coatings. Fire retardants containing corrosive substances were often and repeatedly used in the Czech Republic on many wooden building constructions. This process of chemical corrosion is in practise called as "surface defibering of wood".*

This contribution presents standard and special experimental methods used for measuring the selected mechanical characteristics (compression strength, tension strength, bending strength, hardness and impact resistance) in the damaged surface layer of wooden construction elements. The material for experimental measuring was a construction element removed from a historical roof (ca 150 years old). Mechanical characteristics of the surface layer of the defibered element were compared with the values measured in the deeper subsurface layer of non-damaged wood.

The results of the experiments proved loss of cohesive strength and decrease of mechanical characteristics of wood only in a thin surface layer.

Keywords*: wood, corrosion, defibering, mechanical properties*

1. INTRODUCTION

Antifire protective coatings of wood were used already in ancient times; we can find their signs on surface of historical constructions (Drdácký et al. 2005). Research of chemical compounds and progress of chemical industry enabled development and further intensive application of new fire retardants on wooden elements of standard building constructions.

By research of building constructions treated in the past, it was found out that some chemicals contained in the applied agents cause chemical reactions that damage wood polymers – cellulose, hemicellulose and lignin. Application of fire retardants based on ammonium sulphate and ammonium phosphate, e.g. in brewery in Děčín can be mentioned as an example. Application of agents containing these substances caused damage to the surface layers of wood, commonly called as "surface defibering" (Figure 1).

Wood defibering is now considered as mainly aesthetical defect, causing loss of information from the surface of construction elements. Defibering causes also erosion of wood structure that could gradually lead to significant decrease of mechanical parameters of wooden elements. The effect of fire retardants on strength of wood was described in several articles (LeVan a Winandy, 1990; Winandy, 1995; Winandy, 1997; Winandy et al, 1998). For agents that were used on Czech and Moravian monuments, the problem of chemical corrosion has not been analyzed so far.

Figure 1: Defibered surface of the construction element

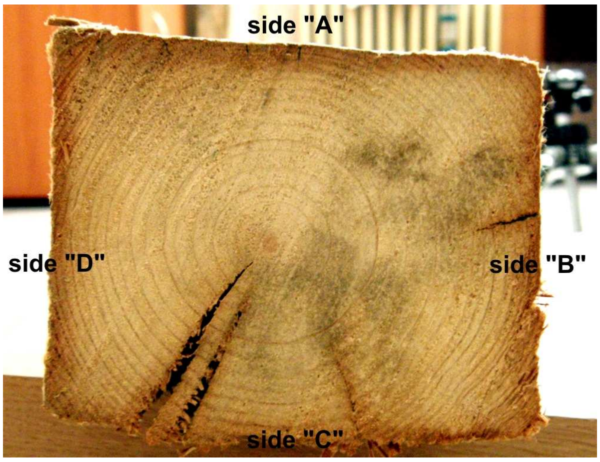

Figure 2: Cross-section of the construction element

2. EXPERIMENTAL PROGRAM

By research of damaged wooden construction elements „in situ“, it was found out that the defibered surface of wood shows significant loss of cohesive strength and other mechanical characteristics. That is why the aim of the laboratory tests was to evaluate to what depth the defibering goes and how significantly this damage influences mechanical characteristics of construction elements. The evaluation of mechanical characteristics of wood was made with use of both standard and non-standard methods, carried out on specimens in laboratory conditions.

Experimental specimens were made of spruce (*Picea abies* (L.) Karst.) collar beam from malt house roof construction of the former brewery in Děčín. Mechanical tests (compression strength, tension strength, bending strength, hardness and impact resistance) were carried out on specimens prepared from the surface layer of the element, damaged by defibering and compared to reference samples made from the inner (non-damaged) part. Preparation of specimens was carried out in accordance with the scheme (Figure 3), which corresponds to cross-section of a girder (Figure 2).

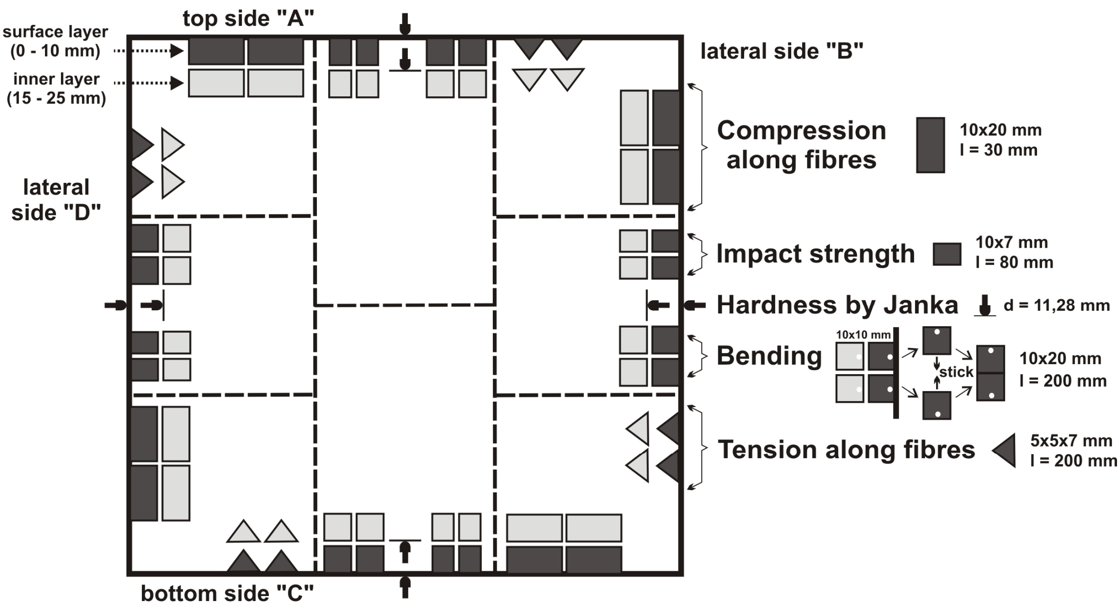

Figure 3: Scheme – preparation of specimens

The monitored characteristics were as follows: strength and modulus of compression along fibres, tested on scantlings with dimensions 20×10×30 mm. The scantlings were made from the surface part (layer 0-10 mm, 45 pcs) and the inner part (layer 15-25 mm, 30 pcs). Strength and modulus of elasticity in tension along fibres were evaluated on micro-specimens with triangular section 5×5×7 mm, length 200 mm. Special tensile micro-specimens enable more accurate determination of the monitored characteristics. The tensile specimens were made again from the surface part (18 pcs) and the inner part (19 pcs) of the girder. Hardness of wood was measured by Janka method on the surface of the elements and in the depth of 15 mm below the surface. In the surface part, measuring was carried out in 56 points, and in 59 points in the inner part. Bending strength and bending modulus of elasticity were tested on scantlings with dimensions 20×10×200 mm. The tested, 20 mm high bending scantlings were made by sticking the scantlings with cross-section 10×10 mm together (Figure 3), from the surface part (6 pcs) and from the inner part (7 pcs). Breaking work was tested on scantlings with dimensions 7×10×80 mm, made again from the surface (20 pcs) and the inner (20 pcs) part of wood. All mechanical tests were carried out in laboratory conditions with wood moisture 12 %.

or the tests of mechanical characteristics, only specimens with no material defects (knobs, cracks, wood-damaging insect and decay) were selected.

3. RESULTS AND DISCUSSION

Limit of compression along fibres and modulus of compression along fibres were higher for specimens from the surface part of wood than for the specimens from the inner part of wood (Figure 4, 5). We attribute this result to higher density of the surface layer of wood (layer 0-10 mm), which contained narrow annual rings, in contrast to the inner part (layer 15-25 mm) where the annual rings were wider. The difference in density is caused by decrease of average annual ring width along the trunk radius and by increase of percental representation of summer wood in particular annual rings (Gryc and Holan, 2004).

Wood structure had, in our case, more significant effect on the given mechanical characteristics than the defibering of the surface of the element. This fact proves the conformity of the measured mechanical characteristics values (Fig. 4,5) with wood density (Figure 6). Compression strength along fibres was related with wood density, which is confirmed by the determination coefficient R^2 = 0,717 (Figure 7).

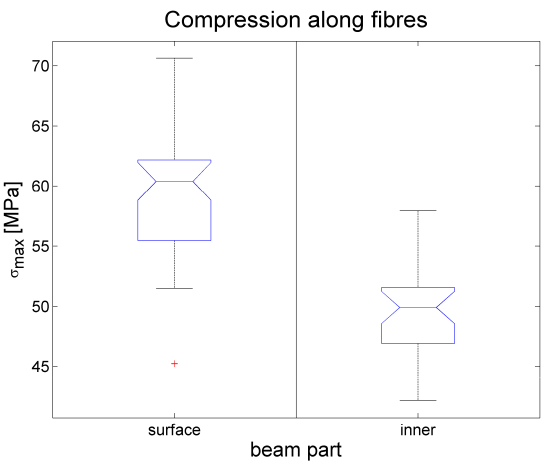

Figure 4: Compression strength along fibres for the surface and the inner part (20×10×30 mm)

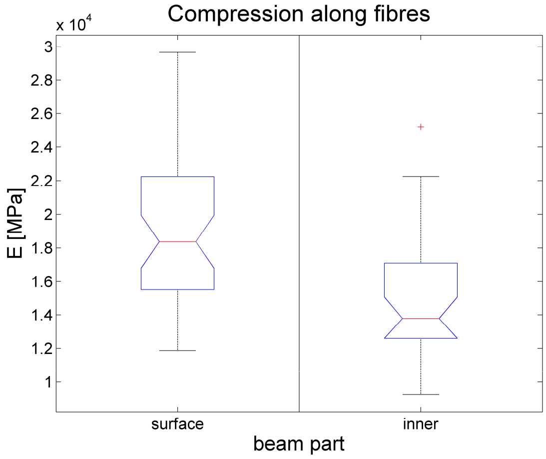

Figure 5: Modulus of compression for the surface and the inner part (20×10×30 mm)

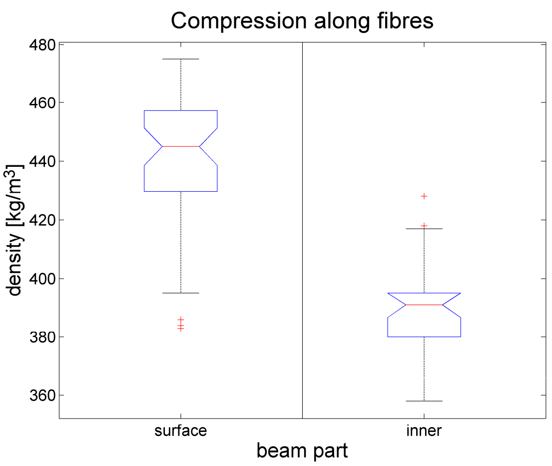

Figure 6: Density of specimens for the surface and the inner parts (20×10×30 mm)

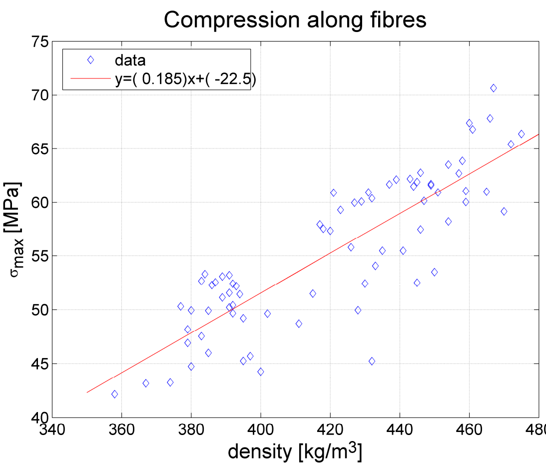

Figure 7: Dependence of compression strength along fibres on density for all specimens (20×10×30 mm)

The test of wood in tension along fibres showed significant decrease of strength in the surface layer of the element caused by degradation of wood mass. The measured strengths of specimens made from the surface parts were 56,3 MPa on average, in spite of their higher density. The strengths of specimens made from the inner part were ca 69,3 MPa (Figure 8), which corresponds to values described in literature for non-damaged spruce wood (Bodig and Jane, 1993).

The average value of modulus of elasticity in the surface defibered layer was higher by 7,5 % compared to the values of specimens from the inner layer (Figure 9). This result was probably influenced mainly by wood density, low number of annual rings and significant share of spring wood in specimens from the inner part of the element. The reason can be seen in a different mechanism of effect of corrosion on summer and spring wood and in the role of these components for tension along fibres, where the effect of spring wood is very low during tension. Apart from the effect of wood structure and density, it is also necessary to take into consideration high variability of characteristics.

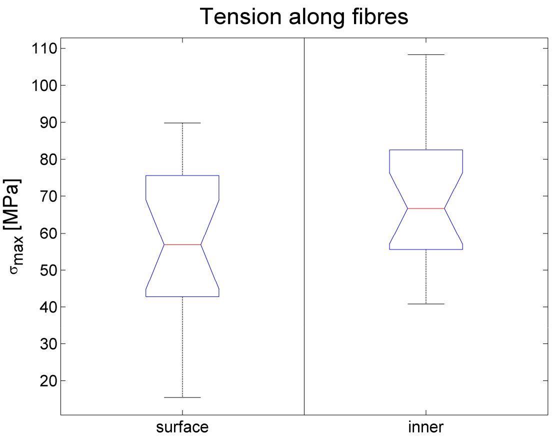

Figure 8: Tension strength along fibres for the surface and the inner part (5×5×7,5 mm)

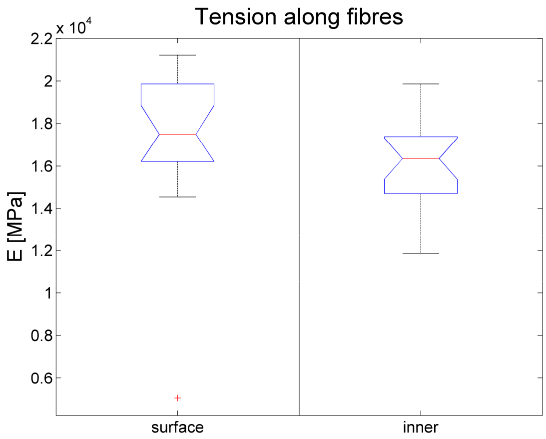

Figure 9: Modulus of elasticity along fibres for the surface and the inner part (5×5×7,5 mm)

For bending specimens prepared from the surface part of wood, the average value of bending breaking strength was 81,1 MPa and bending modulus of elasticity was 55611 MPa (Figure 10, 11). For specimens prepared from the inner part, the average value of bending strength was 79,4 MPa and bending modulus of elasticity was52803 MPa (Figure 10, 11). Values of both characteristics are therefore comparable in both parts of wood. The values measured in the surface part of wood show higher variation. Specimens from the surface part show also significantly higher density (Figure 12). Comparable average values of bending strength and bending modulus of elasticity, in both surface and inner parts of wood, could confirm the effect of defibering that caused the change of mechanical characteristics of wood in the surface layer of the construction element. However, it is necessary to take into account high variation of both characteristics (caused probably by insufficient number of measurings), especially for specimens from the surface parts of the construction element.

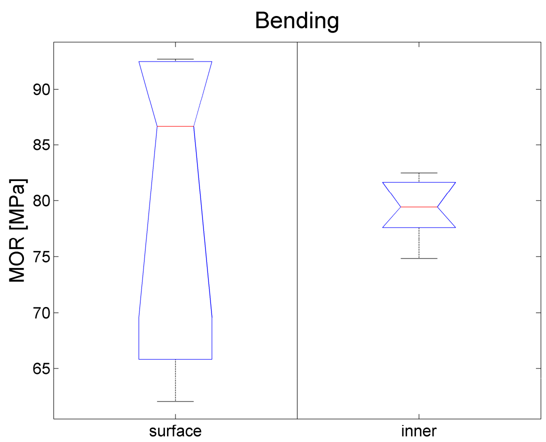

Figure 10: Bending strength for the surface and the inner part (20×10×200 mm)

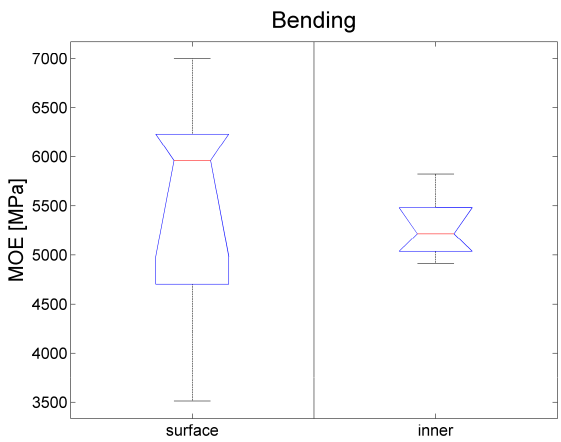

Figure 11: Bending modulus of elasticity for the surface and the inner part (20×10×200 mm)

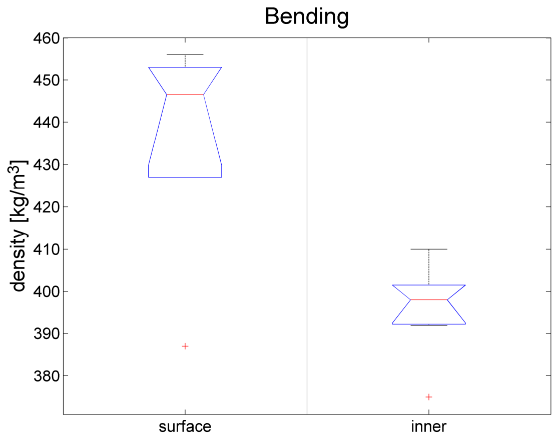

Figure 12: Density of bending specimens from the surface and the inner part (20×10×200 mm)

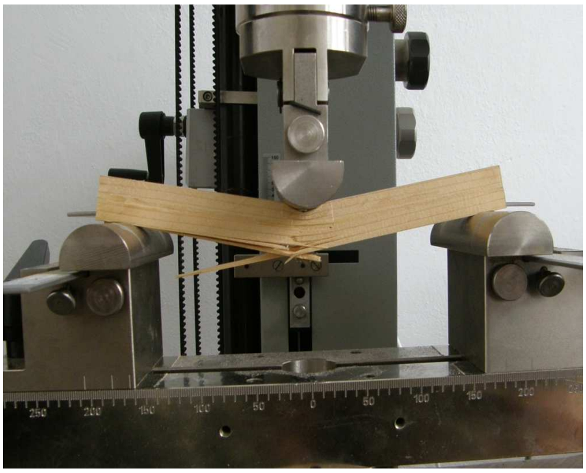

Figure 13: Bending strength test

Hardness measuring by Janka method describes the change of characteristics in a relatively thin layer of the construction element. The average values of hardness measured were 16,7 MPa in the surface part of wood and 16,6 MPa in the inner part. That means that they are nearly the same (Figure 14). However, due to higher density of the surface layer of wood, this result confirms relative decrease of hardness of the surface of the element caused by its defibering.

During the breaking work test, energy required for breaking the specimens with cross-section 10x7 mm (without a notch) was measured. The hammer blow was made in radial direction to the shorter side of the cross-section of testing scantlings. Specimens prepared from the surface layer had higher density and also higher measured impact energy, 4,6 J on average. Specimens prepared from the inner layer of wood had lower density and also lower measured impact energy, 3,6 J on average (Figure 15). Variation of the measured values in the surface layer was significantly lower than in the inner layer; with regard to the difference of densities and impact energies ratio, it is obvious that defibering of wood surface influences its impact strength only minimally.

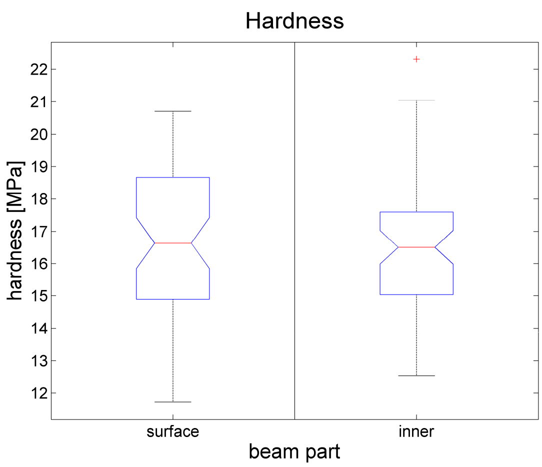

Figure 14: Hardness measured by Janka for the surface and the inner part

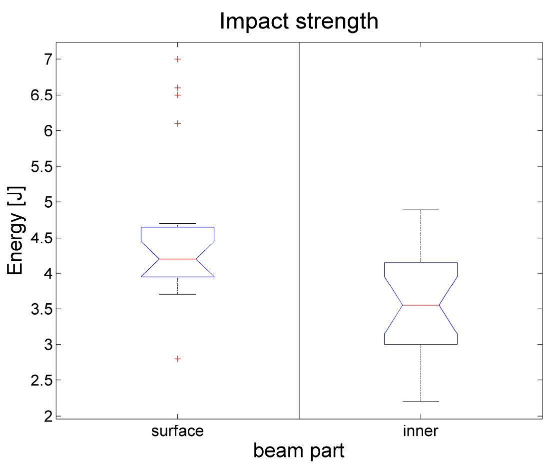

Figure 15: Breaking works for the surface and the inner part (10×7×80 mm)

4. CONCLUSION

From results of the laboratory tests carried out, it is obvious that significant decrease of mechanical characteristics of elements damaged by surface defibering affects only the surface parts of wood of construction elements, maximally to the depth of few millimetres.

Comparison of the values measured in the surface and central zones of the element is complicated by high variability of characteristics, together with influence of other factors. In spite of quite high number of repeating the experiment (except bending), variation of values is high and the difference between arithmetic averages is often not conclusive. The effect of different width of annual ring in both zones is also important, influencing representation of summer wood and specific density and therefore also the monitored mechanical characteristics. During interpretation of results, it is necessary to take into account the actual negative effect of corrosion and positive effect of wood structure.

Relative decrease of wood in the damaged layer demonstrated itself mainly during the tests in tension along fibres. The effect of defibering was evident also from the hardness and bending tests. In the test of mechanical characteristics of wood in compression along fibres and breaking work, the effect of the surface defibered layer on mechanical characteristics of wood was not so significant, with regard to the size of specimens.

In terms of mechanical characteristics, the effect of defibering of the surface layers on load capacity and inflexibility of the construction elements is insignificant. However, during repeated defibering of wood after surface polishing or ineffective neutralisation of acting chemical compounds, reduction of cross-section of the construction elements can happen, resulting in decrease of their inflexibility and load stability. Defibering also supports increase of moisture and possibility of fungal attack.

5. ACKNOWLEDGEMENTS

This contribution was made with support from GAČR 103/07/1091; MSM 6215648902; AV0Z20710524.

6. REFERENCES

Bodig, J., Jayne, B.A. Mechanics of wood and wood composites. 2[a]ed Krieger Publishing company, 1993, 712 pp.

Respective Czech National Standards (ČSN)

Drdácký, M.F., Jirovský, I., Slížková, Z.: On structural health and technological survey of historical timber structures, in Procedings „Conservation of Historic Wooden Structures“ (G.Tampone, ed.), Vol.1, pp. 278-284, Collegio degli Ingegneri della Toscana, Florence 2005.

Gryc, V., Holan, J. Vliv polohy ve kmeni na šířku letokruhu u smrku (Picea abies /L./ Karst.) s výskytem reakčního dřeva. /Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis./ 2004. č. 4, s. 59--72. ISSN 1211-8516

LeVan, S.L., Winandy, J.E.: Effects of fire retardant treatments on wood strength: a review, Wood and Fiber Science, 22(1), 1990, pp.113-131.

Winandy, J.E., Lebow, P.K., Nelson, W.: Predicting bending strength of fire- retardant-treated plywood from screw-withdrawal tests, Res. Note FPL-RP-568, Madison, WI: US Dept. of Agriculture, Forest service, Forest Products Laboratory, 1998.

Winandy, J.E.: Effects of fire retardant retention, borate buffers, and redrying temperature after treatment on thermal-induced degradation, Forest Products Journal, 47(6): pp.79-86, 1997.

Winandy, J.E.: Effects of fire retardant treatments after 18 months of exposure at 150°F (66°C), Res. Note FPL-RN-0264, Madison, WI: US Dept. of Agriculture, Forest service, Forest Products Laboratory, 1995

7. RESPONSIBILITY NOTICE