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# THE INFLUENCE OF CYCLIC STRESS ON THE ATTENUATION RATE OF DEFLECTION OF SOLID WOOD AND LAMINATED WOOD

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## ABSTRACT

In this study, the influence of cyclic stress on the attenuation rate of deflection of solid beech wood and laminated wood was examined. Various thicknesses were evaluated. To aid in this study, a testing method consisting of bending via three-point loading was developed. The attenuation rate of deflection was measured for test samples that were not subjected to cyclic loading and results were compared with those gathered for test samples that were cyclically loaded. Results show that when a higher attenuation rate of deflection is desired, it is suitable to use thicker materials. The type of material and the number of loading cycles were not shown to have a significant effect within the measured range of values.

KEYWORDS: Cyclic loading, laminated wood, beech wood, attenuation rate of deflection.

## INTRODUCTION

Lamination is one of the technologies, where the resulting product is a wood composite material - lamella. This technology is known mainly in the U.S., Canada and Scandinavian countries, but there is most often used in construction and not in the furniture industry. In Slovakia, the lamellae are mainly used for the production of some parts for bed furniture.

Laminated veneer lumber is produced by combining of thin wood veneers. Used veneers are usually 3 mm thick and are made by slicing (Glos et al. 2004, Frese and Blaß 2006). Direction of fibers in all veneers of laminated veneer lumber is parallel to the length of the finished products. The resulting product has an improved mechanical properties and good dimensional stability compared to solid wood, which is why it is increasingly wider application in the production of finished products for various purposes. The production of laminated wood can be used both hard and soft woods, depending on the needs of the customer. It is also possible combination of different types of wood according to their strengths - e.g. outer layers of lamellae composed of softwood for aesthetic appearance and inner layers made from hardwood to achieve higher strength (Gáborík et al. 2011).

To produce laminated wood, solid wood and/or laminated wood are used. The solid wood pieces can vary in thickness and the laminated wood pieces can vary in both number of lamellas and lamella thickness. The lifetime of the final product is influenced by the actual material properties of the wood used. As a result, the lifetime of furniture components varies considerably. The properties of furniture components also change throughout their long-term use. Over time, components can cease to function as intended (Brutovský 2013, Gaff 2003, Gáborík and Dudas 2006, 2008).

Fatigue strength of wood under different loading conditions has been studied by many authors, either for natural or for laminated wood (Bao et al. 1996). Most of researches regarding the fatigue of wood have concerned testing in flexure (Kyanka 1980). Fatigue bending strength of solid wood is not very different for the various species and is lower than that of laminated timber (Sterr 1963). However, the fatigue strength of laminated wood is affected by the type of adhesive used (Ota and Tsubota 1966, Bomba et al. 2014). The fatigue strength of wood is actually much higher than those other crystalline materials when compared to the static strength limit of the substance. Therefore, wood is most widely used for flooring, beams, structural elements etc. in construction industry (Bond and Ansell 1998).

There are many experimental methods by which the physical and mechanical properties of materials used in furniture production can be determined. Despite this, there have been no known procedures for evaluating the “attenuation rate” of wooden furniture components. This “attenuation rate” is the rate at which the parts return to their original state after stressing forces are released. This paper introduces some suggestions as to how to measure and evaluate such utility properties (Gaff 2003). The material is “fatigued” if measured values of attenuation rate of deflection after cyclical loading are decreased when compared to the values before loading. This characteristic plays a very important role in the production of certain furniture components and can affect the comfort of sitting or lying.

The purpose of this work was to understand the influence of cyclic loading on the attenuation rate of deflection of native and on laminated beech wood.

## MATERIAL AND METHODS

The purpose of this work was to determine the influence of cyclic loading on the attenuation rate of deflection of solid beech wood and laminated wood. Bending was done in the radial direction. The attenuation rate of deflection was observed after 1.000, 2.000, and 3.000 cycles. To identify the impact of material thickness on the attenuation rate of deflection, tests were carried out on samples with thicknesses of 4, 6, 10, and 18 mm, subjected to the identical numbers of loading cycles (Maro 2012, Brutovský 2013). Each thickness group of both laminated and solid wood contained 10 samples for each cycle type.

This study examined the influences of material thickness, type of material, and number of stressing cycles on the attenuation rate of deflection. Laminated wood was glued by PVAC adhesive Duvilax D3 Rapid, with the following parameters:

- dry matter content: 49 %,
- viscosity: 4000 - 8000 m Pa.s,
- pH: 3-4,

- min. film-forming temperature: 10°C,
- working time: 10 minutes,
- working temperature: 15-100°C,
- drying time at 20°C: 10 - 30 minutes,
- wood moisture content: 8 %.

## Attenuation rate of deflection

Measurement of the attenuation rate of deflection was done using a special apparatus designed during this study. The apparatus includes a high-speed camera which records and evaluates the behavior of the components throughout the test. The loading force applied was 90 % of the average force required to damage components. After reaching 90 % of the average maximum force, the loading force was released and the sample was allowed to return to its original state. The maximum force value was chosen to ensure that the limitations of the materials were never exceeded (Tab. 1). This ensured that test samples were stressed only in the flexible region and were not damaged. The high-speed camera recorded the return of the test sample to its original state. The trajectory and duration of the sample's return to equilibrium were recorded.

*Tab. 1: Specific parameters for individual thickness group.*

| **Laminated wood** | | | | **Solid wood** | | | |
|---|---|---|---|---|---|---|---|
| **Thickness (mm)** | **Ultimate bending strength (MPa)** | **Limit of proportionality (MPa)** | **90 % of limit of proportionality (MPa)** | **Thickness (mm)** | **Ultimate bending strength (MPa)** | **Limit of proportionality (MPa)** | **90 % of limit of proportionality (MPa)** |
| 4 | 150.1 | 105.1 | 94,6 | 4 | 185.4 | 129.5 | 116.6 |
| 6 | 146.0 | 102.2 | 92.0 | 6 | 178.4 | 117.5 | 105.8 |
| 10 | 120.3 | 84.7 | 76.2 | 10 | 152.0 | 103.4 | 93.1 |
| 18 | 100.4 | 73.4 | 66.1 | 18 | 146.9 | 97.8 | 88.0 |

After each test, the attenuation rate of deflection was calculated according to the Eq. 1,

$$v = \frac{s}{t} \tag{1}$$

where: $v$ - the attenuation rate of deflection (m.s$^{-1}$),
$s$ - the trajectory or flexure (m),
$t$ - the time/duration (s).

In order to compare the attenuation rates of deflection for samples of differing dimensions, the cross-sectional area was taken into account. The instantaneous deflection was calculated with relation to the cross sectional area according to STN 490115 1979 and Eq. 2,

$$y_0 = \frac{F * l_0^3}{4 * b * h^3 * E_0} \tag{2}$$

where: $y_0$ - the instantaneous deflection (mm),
$F$ - the loading force (N),
$E_0$ - the modulus of elasticity (N.mm$^{-2}$),
$l$ - the support span when tested ($l_0 = 20 \times h$) (mm),
$b$ - the width of test sample (mm),
$h$ - the height of test sample (mm).

Taking the cross section into account when calculating the attenuation rate of deflection and combining equations (1) and (2) yields Eq. 3:

$$v = \frac{y_0}{t} = \frac{\dfrac{F * l_0^3}{4 * b * h^3 * E_0} * 0.001}{t} \tag{3}$$

Fig. 1 illustrates the possibilities which, depending on the properties of laminated wood, can influence the attenuation rate of deflection. Fig. 1a illustrates the three-point loading of a piece of laminated wood before stress is applied. Fig. 1b illustrates the laminated wood loaded to the maximum force value ($\sigma_u$). After the external mechanical forces are released (Fig. 1c), the laminated wood returns to its original state and stabilizes depending on its properties (Fig. 1d).

*Fig. 1: Illustration of test of attenuation rate of deflection.*

## RESULTS AND DISCUSSION

### Solid wood

P-values in Tab. 2 show that varying the number of stressing cycles had no significant effect on the attenuation rate of deflection. This observation is confirmed by the graph in Fig. 2. The thickness of the material does significantly affect the attenuation rate of deflection, as shown in Tab. 2 and Fig. 3.

*Tab. 2: Attenuation rate of deflection for solid wood.*

| Monitored factor | Sum of squares | Degrees of freedom | Variance | Fisher T-test | Level of significance P |
|---|---|---|---|---|---|
| Intercept | 17.67228 | 1 | 17.67228 | 1166.113 | 0.000000 |
| Number of cycles | 0.01861 | 3 | 0.00620 | 0.409 | 0.748434 |
| Thickness | 8.13886 | 3 | 2.71295 | 179.015 | 0.000000 |
| Number of cycles × thickness | 0.14295 | 9 | 0.01588 | 1.048 | 0.446788 |
| Error | 0.24248 | 16 | 0.01515 | | |

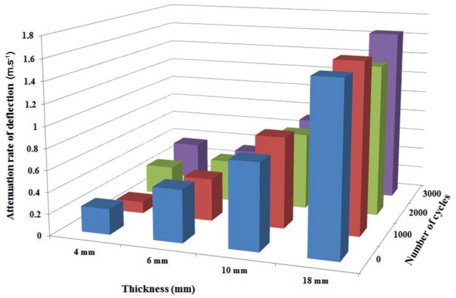

*Fig. 2: The effect of numbers of cycles and thickness on the attenuation rate of deflection for solid wood.*

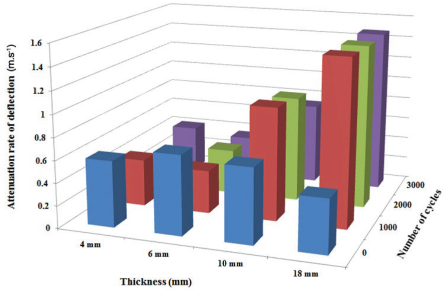

*Fig. 3: The effect of numbers of cycles and thickness on the attenuation rate of deflection for laminated wood.*

## Laminated wood

Results similar to those for native, solid wood were obtained for laminated wood (Tab. 2). The material thickness significantly affected the attenuation rate of deflection (Fig. 3). As thickness increases, attenuation rate of deflection increases.

The number of cycles, as shown in Tab. 3 and Fig. 3, did not significantly affect the attenuation rate of deflection.

*Tab. 3: Attenuation rate of deflection of laminated wood.*

| Monitored factor | Sum of squares | Degrees of freedom | Variance | Fisher T-test | Level of significance P |
|---|---|---|---|---|---|
| Intercept | 17.37535 | 1 | 17.37535 | 1236.315 | 0.000000 |
| Number of cycles | 0.20105 | 3 | 0.06702 | 4.768 | 0.014664 |
| Thickness | 3.47088 | 3 | 1.15696 | 82.322 | 0.000000 |
| Number of Cycles × Thickness | 1.77578 | 9 | 0.19731 | 14.039 | 0.000005 |
| Error | 0.22487 | 16 | 0.01405 | | |

These results (attenuation rate of deflection grow up with increasing of material thickness) also correspond with results of other authors that if we keep a conditions of slenderness ratio (20 × material thickness) the attenuation rate of deflection raise up because of increasing of material length. This fact is heterogeneous distribution of properties on larger material length. We should look for other possibilities of modification for these materials because of improving utility properties for purposes of furniture creation. Similar observations have been made before (Macek 2013).

## CONCLUSIONS

1. Results for solid, native wood show that the thicker the material is, the greater the attenuation rate of deflection is. The effect of the number of cycles on the attenuation rate of deflection is statistically insignificant. Similar results were obtained for samples made with laminated wood.

2. There was no significant difference between the behaviors of solid wood components and laminated wood components. A slightly higher value of attenuation rate of deflection was measured for solid wood with a thickness of 18 mm.
3. If one desires higher attenuation rates of deflection, thicker materials should be used. The type of material and number of stressing cycles were shown to have no significant effects on the attenuation rate of deflection.

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## REFERENCES

1. Bao, Z., Eckelman, C., Gibson, H., 1996: Fatigue strength and allowable design stresses for some wood composites used in furniture. Holz als Roh- und Werkstoff 54(6): 377-382. DOI: 10.1007/s001070050204.
2. Bomba, J., Cvach, J., Šedivka, P., Kvietková, M., 2014: Strength increase pattern in joints bonded with PVAc adhesives. BioResources 9(1): 1027-1037. DOI: 10.15376/biores.9.1.1027-1037.
3. Bond, I.P., Ansell, M.P., 1998: Fatigue properties of joined wood composites: Part I. Statistical analysis, fatigue master curves and constant life diagrams. Journal of Material Science 33(11): 2751-2762. DOI: 10.1023/A:1017565215274.
4. Brutovský, T., 2013: Elasticity properties of laminated wood-based materials and non-wood components. (Pružnostné vlastnosti lamelových materialov na báze dreva a nedrevených komponentov). Technical University in Zvolen, 95 pp. Master’s thesis (in Slovak).
5. Frese, M., Blaß, H.J., 2006: Characteristic bending strength of beech glulam. Materials and Structures 40(1): 3-13. DOI 10.1617/s11527-006-9117-9.
6. Gaff, M., 2003: The use of HF - energy for plasticizing of soft deciduous trees for the purpose of bending. (Tvárnenie dreva okysličovaním s využitím vysokofrekvenčnej energie). Technical University in Zvolen. 105 pp. Master’s Thesis (in Slovak).
7. Gáborík, J., Dudas, J., 2006: The change of properties of aspen wood by mechanical treatment – by pressing. Electronic Journal of Polish Agricultural Universities 9(3): #15.
8. Gáborík, J., Dudas, J., 2008: The bending properties of aspen wood. Annals of Warsaw Agricultural University of Life Sciences. Forestry and Wood Technology 65: 55-60.
9. Gáborík, J., Joščák, P., Kulík, J., Grznárik, T., 2011: Properties of compressed laminated beech wood by bending stress. Annals of Warsaw Agricultural University of Life Sciences. Forestry and Wood Technology 74: 63-68.
10. Glos, P., Denzler, J.K., Linsenmann, P., 2004: Strength and stiffness behaviour of beech laminations for high strength glulam. In: Proceeding Meeting 37 CIB Working Commission W18-Timber Structures, paper CIB-W18/37-6-3, Edingburgh, UK.
11. Kyanka, G.H., 1980: Fatigue properties of wood and wood composites. International Journal of Fracture 16(6): 609-616 DOI: 10.1007/BF02265220.
12. Ota, M., Tsubota, J., 1966: Studies on the fatigue of 2 ply laminated wood. I. Several investigations on the static viscoelasticity behaviors of wood subjected to bending test. Journal of Japan Wood Research Society 12(1): 26-30.

13. Sterr, B., 1963: Untersuchungen zur Dauerfestigkeit von Schichtholzbalken. Holz als Roh- und Werkstoff 21(2): 47-61. DOI: 10.1007/BF02609715.
14. STN 490115, 1979: Wood. Determination of ultimate strength in flexure tests.
15. Macek, Š., 2013: Identifying characteristics of veneer based laminated wood in relation to its application in the design of furniture and their modification. (Identifikácia vlastností lamelového dreva na báze dýh vo vzťahu k jeho uplatneniu v konštrukcii nábytku a ich modifikácia). Technical University in Zvolen, 100 pp. PhD. Thesis (in Slovak).
16. Maro, M., 2012: Properties of laminated wood based on veneer molded components. (Vlastnosti lamelového dreva na báze dýhových lisovaných komponentov). Technical University in Zvolen, 100 pp. Master's Thesis (in Slovak).

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