Effect of Cyclic Loading on the Elasticity of Beech Solid and Laminated Wood

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This article deals with the determination of the cyclic loading effect on the elastic modulus (E_m) of beech solid and laminated wood at various thicknesses while bent in the radial direction. To identify the modulus of elasticity, a three-point static bending test was carried out. The monitored characteristics were compared for the bodies under cyclic stress *vs.* bodies not subject to cyclic stress. Results showed no significant effect of cyclic loading on the laminated wood elastic modulus values. Conversely, cyclic loading significantly (95% confidence interval) affects the modulus of elasticity values for solid wood. A significant impact of thickness has been observed for both types of material. The results demonstrate that the elastic modulus values decrease with increasing thickness after cyclic loading.

Keywords: Cyclic loading; Laminated wood; Bending strength; Elastic modulus

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INTRODUCTION

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

Laminated veneer lumber is produced by combining thin wood veneers which are usually 3 mm thick and are made by slicing (Frese and Blaß 2006; Glos *et al.* 2004). The direction of fibers in all veneers of laminated veneer lumber is parallel to the length of the finished products. The resulting product has improved mechanical properties and good dimensional stability compared to solid wood, which is why it has increasingly wider application in the production of finished products for various purposes. Both hard and soft woods can be used for the production of laminated wood, depending on the needs of the customer. Also, a combination of different types of wood is possible 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.* 2012).

The present research aimed to study the effect of cyclic loading of solid beech and laminated wood on their strength properties. The durability (lifetime) of these products varies considerably, which affects the properties of the material itself. Change in the characteristics is caused by long-term use of furniture components, which over time cease to perform the function for which they are intended (Brutovský 2013; Gáborík and Dudas 2006; 2008; Gaff 2009).

The purpose of this work is to study the cyclic loading effect on the elasticity features for beech solid and laminated wood. In practice, either solid wood of different thicknesses or laminated wood with different numbers of lamellae with different thicknesses is utilized for laminated wood fabrication (Gaff and Zemiar 2008). The lifetime of these products varies considerably due to the material properties. In addition, this work will extend the knowledge of the fabrication of these products, which should, to a significant degree, define the impact of the modulus of elasticity on the given mechanical feature to assist in the creation of high-quality furniture products. It is understood that the overall lifetime of the furniture products is affected by the lifetime of the individual elements. A secondary goal of this work was to verify a new testing methology for the verification of materials by means of cyclic stress.

EXPERIMENTAL

Materials

This work is based on experimental determination of the cyclic loading effect on the elastic modulus (E_m) of European beech solid and laminated wood while bent in the radial direction. Splints used for the fabrication of laminated wood were obtained by rotary-peeling of steamed European beech (*Fagus sylvatica*) wood from the Polana region in Slovakia. The samples were conditioned to a moisture content of 8%.

In order to prepare the test pieces from solid wood, boards were selected from its sapwood fraction. From among these boards, parts were chosen from equal distance from the core for the manufacture of test pieces. This ensured equal density of the test pieces. The individual splint layers were also selected from approximately equal distance from the core for the manufacture of laminated wood test pieces.

The laminated wood test pieces were pressed at 60 °C, with a pressing time of 10 min and a specific pressure of 1 MPa. The pressing rate was not higher than 5% from the original thickness of the test pieces. Changes in the modulus of elasticity after 0, 1,000, 2,000, and 3,000 cycles were assessed. To determine the impact of material thickness, the tests were carried out on pieces 4, 6, 10, and 18 mm thick. Figure 1 shows the exact categorization of the individual sets of the test pieces. One set of test specimens was composed of 10 pieces.

Laminated wood was glued with the PVAC adhesive Duvilax D3 Rapid, with the following parameters:

- dry matter content: 49%,
- viscosity: 4000 to 8000 mPa.s,
- pH: 3 to 4,
- minimum film-forming temperature: 10 °C,
- working time: 10 min,
- working temperature: 15 to 100 °C,
- drying time at 20 °C: 10 to 30 min,
- wood moisture content: 8%.

The PVAC adhesive was weighted before the application in order to determine the required adhesive layer. The prepared amounts of adhesive were applied uniformly by means of a hand roller.

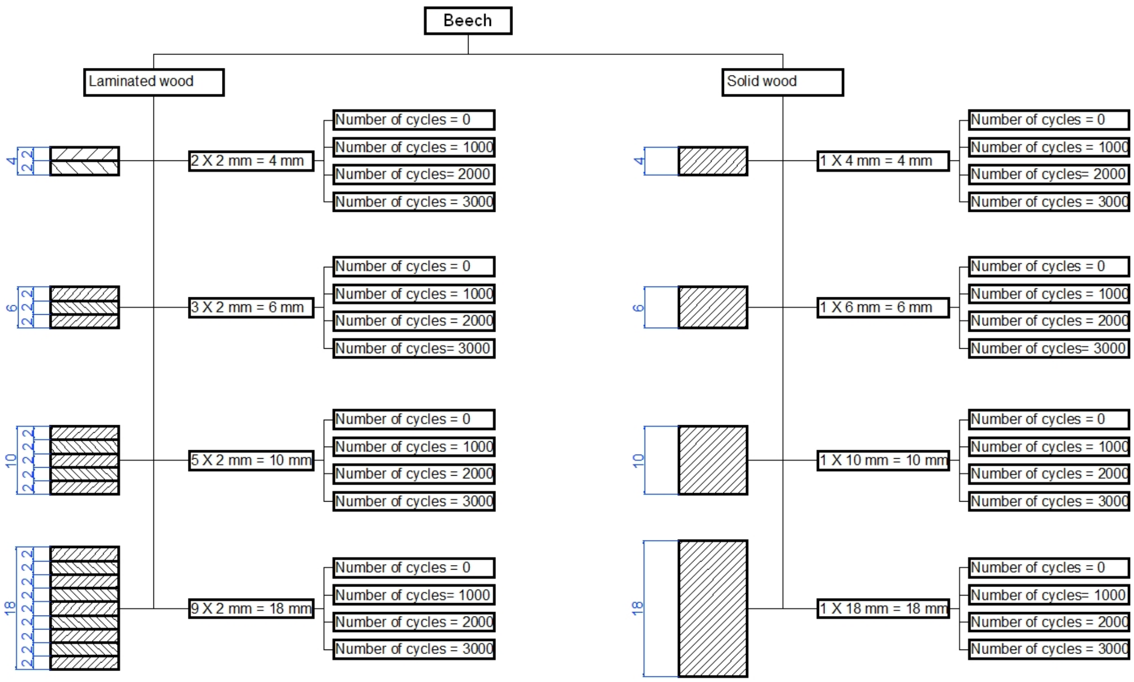


Fig. 1. Categorization of test pieces

Methods

Bending elastic modulus determination

The varying thickness dimensions of test samples must comply with the condition that provides a support span of 20 * h, where h is the thickness of the test piece. The loading rate was set so that the breaking of the test sample occurred at 1.5 ± 0.5 min from the start of loading. Flexure was measured at the center of the test sample under a bending pin with an accuracy of 0.1 mm, and the measured value was recorded together with the corresponding load and measured with an accuracy of 1% of the measured values of Fig. 2. Break loading, with an accuracy of 1% of the measured value, was recorded.

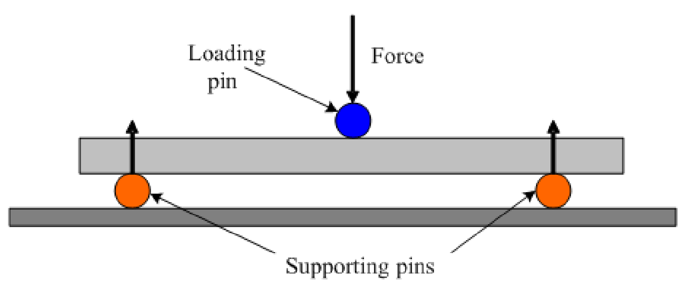


Fig. 2. Basic principle of three-point bending test. The experiments of bending elastic modulus measurements, perpendicular to the fibers in radial direction, were carried out according to the standard STN EN 490115 (1979)

The bending elastic modulus values were computed using Eq. 1,

$$E_m = \frac{l_0^2 * (F_2 - F_1)}{4 * b * h^3 * (a_2 - a_1)} \quad \text{[MPa] (STN EN 490115)} \tag{1}$$

where E_m is the elastic modulus perpendicular to the fibers in the radial direction [MPa], l_0 is the axial distance between supports [mm], b is the test piece width [mm], h is the test piece thickness [mm], and $F_2 - F_1$ is the loading increase in the loading/deflection curve linear section [N]. The value of F_1 should be approximately 10% and F_2 approximately 40% of the breaking load. The difference $a_2 - a_1$ is the deflection increase in the half of the test piece length (corresponding to the loading increase $F_1 - F_2$).

Cyclic bend loading

The cyclic loading was carried out on a cycler machine (Fig. 3) with cyclic bending of the test pieces using single-axis loading. The following numbers of cycles were selected for testing: 0, 1,000, 2,000, and 3,000. During the preliminary experimental testing, the test pieces were loaded with static bending to determine the breaking strength and proportionality limit because the test pieces had to be loaded up to 90% of the proportionality limit.

Fig. 3. Cycler machine

Statistical analysis

For the evaluation of results, a two-factor variance analysis evaluation of the effect of individual factors on the modulus of elasticity of solid wood and laminated wood was used. Based on the P-level value, it was determined whether the monitored factor affected the values of the modulus of elasticity. The achieved results were processed by the mean of diagrams showing a 95% confidence interval.

RESULTS AND DISCUSSION

Laminated Wood

Based on Table 1 and the significance level P = 0.202, it may be concluded that the number of cycles had no statistically significant effect on the elastic modulus of the laminated wood. The results shown in the diagram of 95% confidence interval (Fig. 4) also confirms this conclusion. The number of cycles being monitored may be considered as low for this purpose in case of laminated wood lifetime testing. In future work it is recommended to focus on the investigation of the effect of higher numbers of cycles.

Figure 5 shows that the elastic modulus values changed significantly with changes in the laminated wood thickness, as confirmed also by the significance level P = 0.0000001 given in Table 1. This diagram shows that with increasing material thickness, the elastic modulus values decreased, except for the elastic modulus value found for the 6-mm-thick laminated wood where a statistically significant increase in the modulus of elasticity values can be seen.

The interaction of both monitored factors (laminated wood thickness and number of cycles) proved to be a combination of statistically significant factors (Fig. 6, Table 1).

Table 1. Two-factor Variance Analysis Evaluating the Effect of Individual Factors on the Elastic Modulus of Laminated Wood

Monitored factor	Sum of squares	Degrees of freedom	Variance	Fisher's F - Test	Significance level P
Free term	1.555351E+10	1	1.555351E+10	6425.379	0.0000001
Number of cycles	1.133184E+07	3	3.777279E+06	1.560	0.201597
Material thickness	2.557202E+08	3	8.524008E+07	35.214	0.0000001
Number of cycles * material thickness	1.012217E+08	9	1.124685E+07	4.646	0.000021
Error	3.485717E+08	144	2.420637E+06		

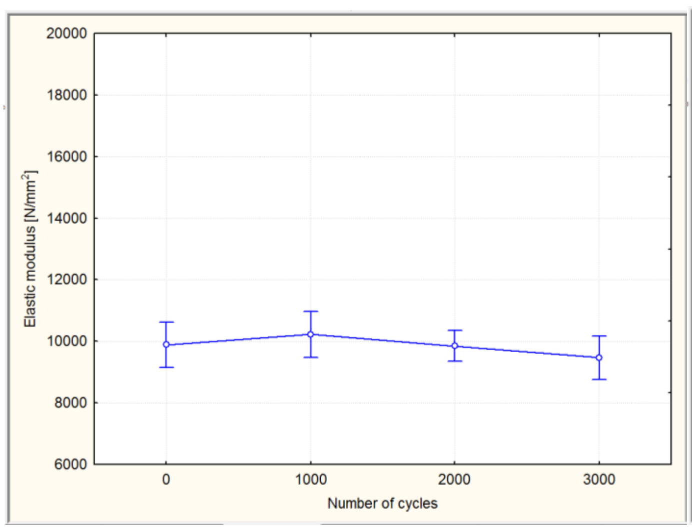


Fig. 4. The effect of the number of cycles on the elastic modulus for laminated wood

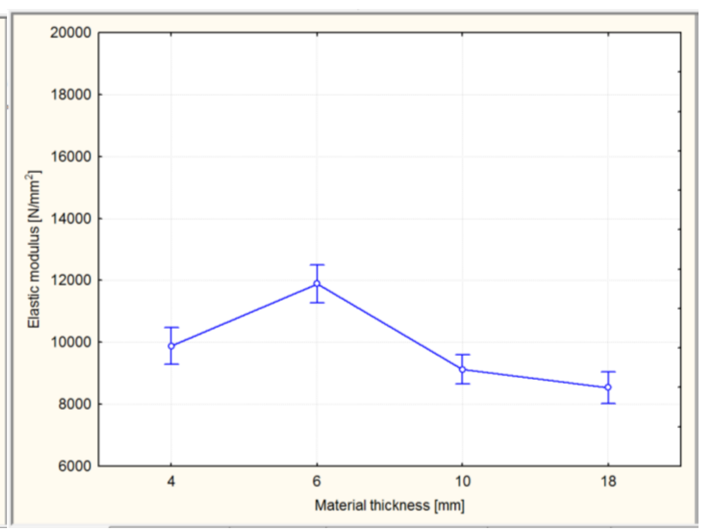


Fig. 5. The effect of the material thickness on the elastic modulus for laminated wood

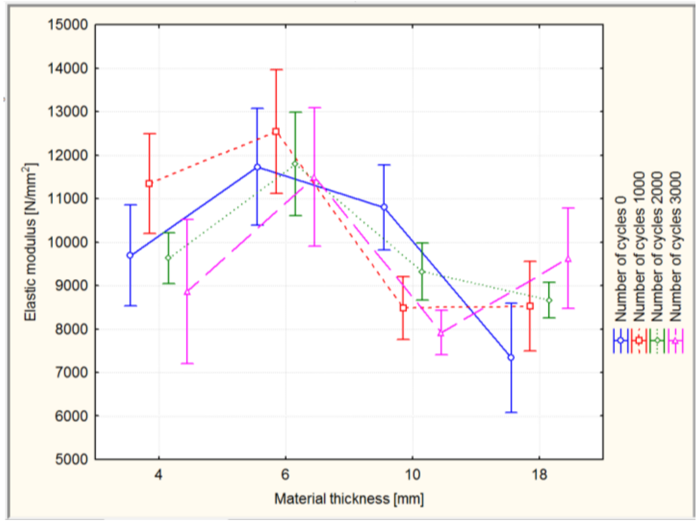


Fig. 6. The effect of both material thickness and number of cycles on the elastic modulus for solid wood

Solid Wood

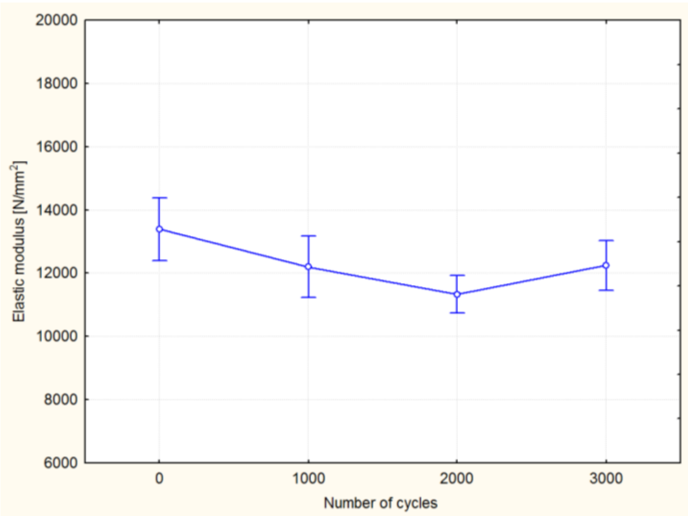
As shown by the values of the significance level in Table 2, the number of cycles, material thickness, and the interaction between these factors significantly affected the statistics of the measured values of the solid wood elastic modulus.

Table 2. Two-factor Variance Analysis Evaluating the Effect of the Individual Factors on the Elastic Modulus of Laminated Wood

Monitored factor	Sum of squares	Degrees of freedom	Variance	Fisher's F - Test	Significance level P
Free term	2.342120E+10	1	2.342120E+10	12470,00	0.0000001
Number of cycles	1.070298E+08	3	3.567661E+07	19,00	0.0000001
Material thickness	6.270167E+08	3	2.090056E+08	111,28	0.0000001
Number of cycles * material thickness	8.628126E+07	9	9.586806E+06	5,10	0.000005
Error	2.704614E+08	144	1.878204E+06		

Figure 7 shows the effect of the number of cycles on the solid wood elastic modulus values. The statistical significance of the decrease in the elastic modulus values with increasing numbers of loading cycles is apparent. The difference between the elastic modulus values found at 2,000 and 3,000 cycles are considered statistically insignificant.

The comparison of cyclic stress effects on laminated wood (Fig. 4) and solid wood (Fig. 7) shows no cyclic stress effect on laminated wood, while on solid wood, there was a statistically significant decrease of the elastic modulus values. Dudas (2010) mentions that the thickness and number of layers influence the bending capability and elastic modulus. Generally, the laminated wood achieves higher bending capability and flexibility than the solid wood. The laminated wood does not exhibit so significant inner structural rupture as the solid wood does. Therefore, the cyclic stress impact was found to be greater for the solid wood.



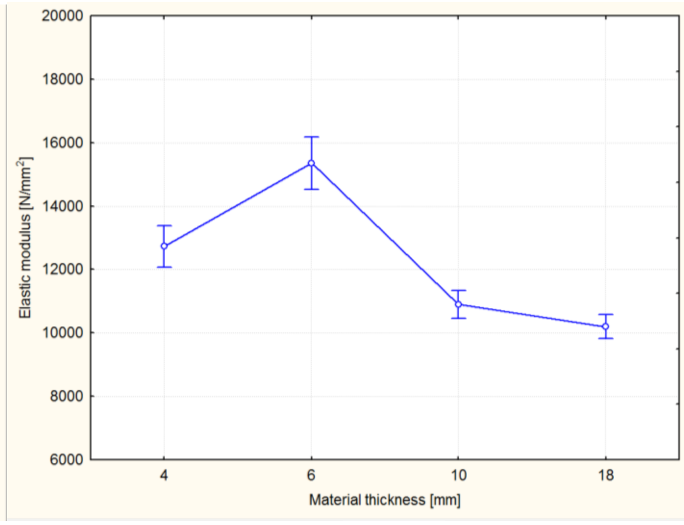


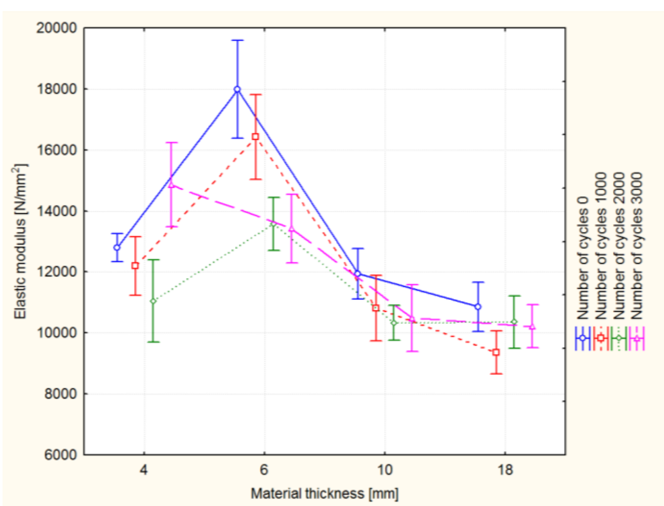
Fig. 7. The effect of the number of cycles on the elastic modulus for solid wood

Fig. 8. The effect of material thickness on the elastic modulus for solid wood

While evaluating the solid wood elastic modulus that was affected by the material thickness (Fig. 8), there was a decrease of the modulus of elasticity, similar to that for the laminated wood; the exception was the set of 6-mm-thick test pieces, where a statistically significant increase in the monitored elastic modulus values was found.

The effect of the interaction between monitored factors (number of cycles and thickness under load), which is shown in Fig. 9, confirms the significance level value of P = 0.000005 (Table 2); the effect of the interaction of both monitored factors was statistically significant.

Figure 10 shows the effect of the number of cycles on the elastic moduli values of both solid and laminated wood.



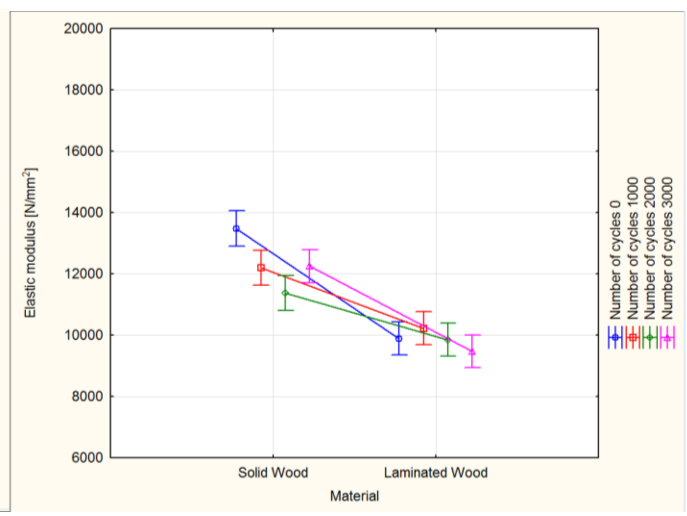


Fig. 9. The effect of both material thickness and number of cycles on the elastic modulus for solid wood

Fig. 10. The effect of both material type and number of cycles on the elastic modulus

The elastic moduli values measured on laminated wood had significantly lower values than solid wood, while the effect of the number of cycles did not produce significant results. For solid wood, there was a decrease in the elastic modulus values for each loading cycle.

CONCLUSIONS

1. No cyclic stress impact was found for laminated wood elastic modulus (at the monitored number of cycles). Therefore, the laminated wood can expect a longer lifetime than the solid wood for this material type and monitored number of cycles.

2. For solid wood, the elastic modulus values decreased significantly with cyclic stressing. Therefore, one may expect that this material lifetime will be significantly lower than that of the laminated wood. These results are comparable with the work of Stark (1997).

3. The different behaviors of solid wood and laminated wood were attributed to the effect of both glue and material composition. Laminated wood is joined by gluing to provide the material, in its entirety, higher resistance against cyclic loading.

4. The measured elastic moduli values for the laminated wood were within the range of 9000 to 11000 MPa. The solid wood elastic modulus values were between 10000 and 13000 MPa. Thus, the solid wood relative to the elastic modulus can be considered to be a better material. Conversely, the laminated wood is more resistant against cyclic loading, and the elastic modulus values did not change.

5. When comparing the effects of the material thickness on the elastic modulus values, one may expect the same effect for both materials, *i.e.*, a decrease of the modulus of elasticity values. Similar results were also measured by Maro (2012).

6. The sets of 6-mm-thick test pieces of both solid and laminated wood constitute an interesting group. For both sets of test pieces, the highest values of the elastic modulus were measured for this thickness. Therefore, these sets of test pieces will be subjected to further research within this area.

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