335. Research of Wood Gluing Factors by a Method of Resonant Oscillations

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Abstract. This paper presents the methodology and equipment that is applied for experimental investigation of glued wood articles and their components by means of resonant vibrations. It is demonstrated that beam and plate, which form wood assortments along and across grain, may be studied by using theoretical calculations based on deformed beam vibrations. In addition, research data of oak glued-up panels of varying width as well as adhesive and scantlings are included. It was determined that the increase of width of the panels (the number of scantlings) practically does not change the shape of their first vibration mode. However, the research revealed slight changes in the amplitude-frequency characteristic, i.e., the first natural frequency increased up to 5 %, and the bandwidth decreased by 30 %. Irrespective of additional factors, the modulus of elasticity of the glued-up panels was higher by 10 % in comparison to average modulus of elasticity of the used scantlings, whereas damping coefficient was lower by 40 %. Obtained results may be used to evaluate the behavior of glued-up panels in the zone of dynamical loads and to produce glued-up panels with proper parameters.

Keywords: scantling, glued-up panel, modulus of elasticity, damping coefficient, resonant vibrations

Introduction

Wood is often glued up in order to obtain assortments of larger diameter, to ensure stability of the dimensions and shape, to avoid occasional imperfections and defects and to make more rational use of fine assortments. Glued-up balk, laminated wood and glued-up panels are attributed to this group of wood material.

Glued-up panels are made of both conifer and leafy wood. They can be single-layer and multi-layer. The structure of glued-up panels, the diameter of scantlings and the method of their joining depend on the panels being used.

One of the requirements for glued-wood products is to have specific viscous elastic properties, i.e. to possess certain values of modulus of elasticity and damping coefficient. For example, assortments used in building constructions, should be resistant to the load of specific magnitude and direction, i.e., they should represent particular tension properties [1]. Usually parts of glued wood are used for noise insulation, „absorption“, or, on the contrary, for its intensification. In the first case, various partition walls, ceilings in buildings [2, 3], ships, planes, and in the second case - accessories of musical instruments, i.e., sounding-boards [4] etc., are produced. Thus, on the one side, wood should posses excellent viscous properties (damping coefficient), and on the other side, it should be characterized by elastic properties. Strength and quality of pasting is usually an object of investigation of glued-up wood. It has been confirmed that the thickness of adhesive seam affects the resistance to mechanical impact [5]. The plasticity of adhesive has influence on mechanical properties of an article [6, 7]. The effect of sort and geometrical parameters on resonant frequency and vibration modes of glued-up panels was studied fairly extensively [8, 9]. However, there are not so many research results on other important characteristics of glued-up wood. Thus, after fabrication of glued-up wood articles it is relevant to estimate not only properties of separate components (adhesives, wood) but the quality of the complete articles as well. Method of resonant vibrations is a suitable technique for the evaluation of relevant wood properties since its application enables characterization of viscous properties (damping coefficient).

The aim of the research is to determine how viscous elastic properties of the glued-up panels are influenced by viscous elastic properties of scantlings, forming single-layer glued-up panels as well as the effect of their quantity and applied adhesive.

Research methods

For the study of wood articles methods of isotropic and anisotropic plates were used [10]. Mechanical properties of wood differ greatly and are expressed in two perpendicular directions – along and across the grain. In this case, wood plates with respect to their properties in these grain directions approach the properties of a beam type body [11].

Applying the system of distributed parameters, the expressions for solid beam modulus of elasticity E and damping coefficient $tg\delta$ are expressed as follows:

$$E = \frac{f_{res}^2 4\pi^2 \rho s l^4}{IA^2} \qquad tg\delta \approx \frac{\Delta f}{f_{res}}; \qquad (1)$$

where f_{res} – resonant frequency, Δf – width of resonance curve in the vicinity of a corresponding frequency, ρ – beam density, l – beam length, I – cross-section inertia moment, s – cross-sectional area; A – coefficient, characterizing the method of clamping of beams ends and its modes.

The research was carried out by means of original experimental set-up [11]. Figure 1 presents the schematics of the set-up that was used for the investigation of viscous elastic properties of wood articles.

Glued-up test panel 1 was freely placed on four elastic elements 2 (Fig. 1). When testing the scantling, it was placed on two elastic elements. These elements were made from foam ($120 \times 120 \times 100$ mm) and fastened to the massive supports 3. An acoustic vibrator 4, driven by the signal generator 5, was used to induce vibrations of the studied assortment 1. These vibrations were registered by a sensor 6 that was attached to the test object 1. When changing the frequency of the generator 5, resonant vibrations of the test object were induced. They were measured by the measuring device 7. The shape of vibrations was observed on the screen of the oscillograph 8. To determine the bending direction of the assortment, vibration phase was measured by the phasometer 9. For this purpose, signals from the measuring device 7 and the generator 5 were transmitted to the phasometer 9.

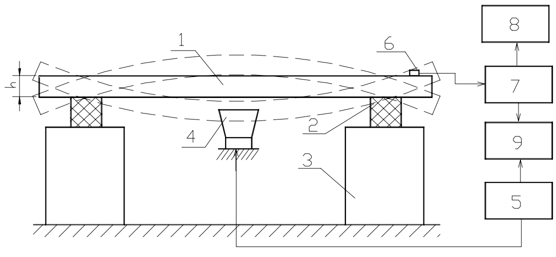


Fig. 1. Set-up for testing wood articles: 1 – wood assortment and its mode; 2 – elastic elements; 3 – massive supports; 4 – acoustic vibrator; 5 – generator of electric oscillations; 6 – sensor; 7 – measuring device; 8 – oscillograph; 9 – phasometer

The tested glued-up panel (scantling) was freely placed on the elastic elements 2 thereby representing extreme conditions of an unfastened plate or beam. Assortment vibrations were measured in the range of 20 – 2000 Hz.

Vibration modes of the scantlings were close to the theoretical beam modes [10, 12]. Vibrating glued-up panels acquired certain modes and the research revealed that in most cases the plate modes were complex. However, modes close to beam modes were recorded as well (Fig. 2). In this case it corresponded to the first beam mode. Therefore, the glued-up panel was analyzed as the beam in both directions of the grain, i.e. beam theory was applied for the estimation of modulus of elasticity and damping coefficient.

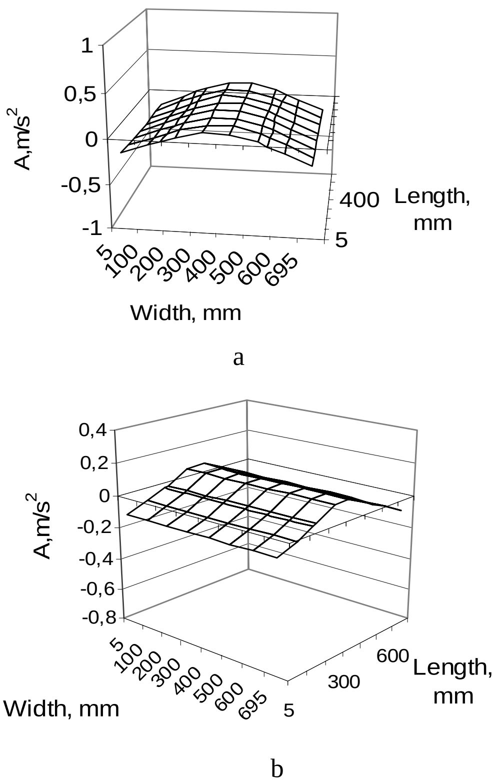


Fig. 2. Vibration modes of the square oak glued-up panel: a – across the grain, b – along the grain

Oak scantlings, which were randomly selected for the research, were cut along and across wood grain. Afterwards they were glued so as to form single-layer glued-up panels, and marked as T_{acr} and T_{al} (across and along grain respectively). Three types of panels were made. Panels of the first type were fabricated by gluing scantlings with similar modulus of elasticity, panels of the second type – by gluing scantlings with decreasing modulus of elasticity, and the third type – by gluing scantlings with a higher and lower modulus of elasticity by rotation. Three types of adhesive were used in the research work – the adhesive of category D2 made on the basis of polyvinyl acetate (PVA) resin, the one of category D4, and polyurethane adhesive of category D4.

Initially, the modulus of elasticity and damping coefficient were determined. Subsequently, the scantlings were glued together at edges under laboratory conditions, and the glued-up panel was tested again thereby determining its modulus of elasticity and damping coefficient. Gluing of scantlings and measurement of vibrations were performed as follows: initially, two scantlings were glued, and after determining the first natural frequency of this compound, its modulus of elasticity was calculated, and damping coefficient was extracted from the obtained amplitude-frequency characteristics. Later, more scantlings were glued on until a square panel was finally obtained. At the same time a variation of the shape of the first mode of the glued-up panel was evaluated. A reverse process was also performed, i.e., viscous elastic properties of the panels were analyzed and later, after cutting them along adhesive joints, properties of the scantlings were evaluated repeatedly.

Research results

The dimensions of oak scantlings cut along fiber were $670\times60\times30$ mm, the density – 680-820 kg/m^3, the humidity was ranging between 10.8-12.9 %. The dimensions of scantlings cut across wood grain were $250\times40\times15$ mm, the density – 640-760 kg/m^3, the humidity was ranging between 7.2-11.3 %. The panels of the first type were made by gluing scantlings, cut along fiber, with the adhesive of category PVA D2, and were relatively marked T_{al11}, T_{al12} and T_{al13}. The second type was marked as – T_{al21}, T_{al22} and T_{al23}, and the third type – T_{al31}, T_{al32} and T_{al33}. The measurements of oscillations were performed in the specific points of assortments thereby evaluating the variation of the shape of the first vibration mode (Fig. 2).

It was determined that the increase of width of the panels (the number of scantlings) practically does not change the shape of their first vibration mode. However, the research revealed slight changes in the amplitude-frequency characteristic, i.e., the first natural frequency increased up to 5 %, and the bandwidth decreased by 30 %.

The consistent patterns of varying average modulus of elasticity and damping coefficient of the panels T_{al11}, T_{al12} and T_{al13} and of scantlings forming them are presented in Figure 3.

Fig. 3 a. indicates that the average modulus of elasticity of scantlings varied from 10655 to 10703 MPa, and the one of panels made of scantlings – from 10966 to 11561 MPa. It was determined that in all cases the modulus of elasticity of the panels was higher by up to 8 %, in comparison to the modulus of elasticity of used scantlings. The average damping coefficient of the scantlings ranged from 0.024 to 0.028, and the one of panels – from 0.020 to 0.0245. The difference between damping coefficients in separate cases was equal to 40 %.

By gluing panels of other types, their mode shapes did not change either and only amplitude-frequency characteristic slightly varied analogically to those of the first type shields.

Analogous results were obtained by gluing panels of the mentioned types with the adhesive of category PVA D4 and polyurethane adhesive of category D4 as well as by gluing scantlings cut across grain.

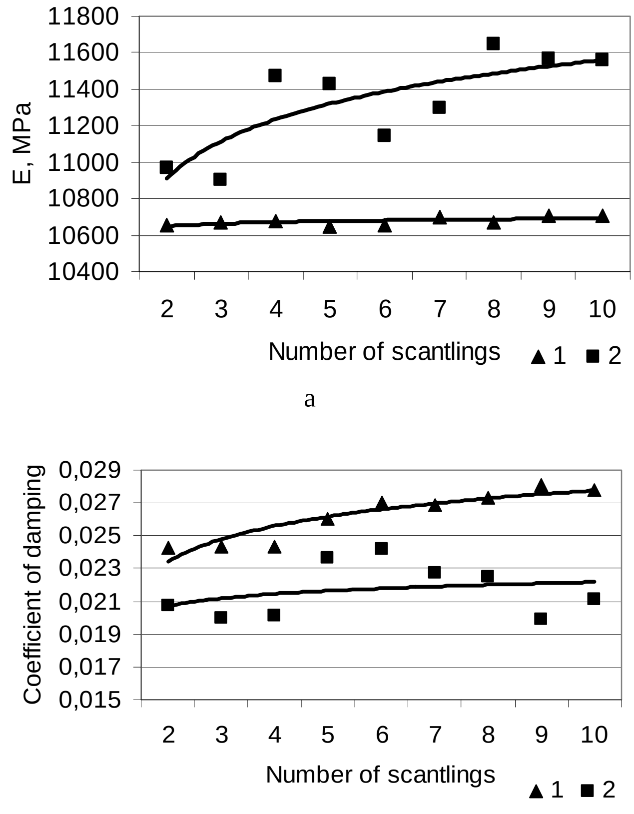
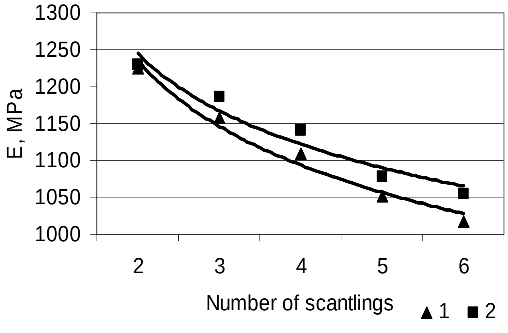


Fig. 3. Consistent patterns of varying average modulus of elasticity (a) and damping coefficient (b) of oak wood scantlings, and of first-type panels made of them (T_{al11}, T_{al12}, T_{al13}): 1 – for scantlings, 2 – for panels

The consistent patterns of varying average modulus of elasticity and damping coefficient for the second type panels (T_{acr21}, T_{acr22}, T_{acr23}) and for the corresponding scantlings made by gluing with the adhesive of category PVA D2, are given in Figure 4.

With an increase in the number of scantlings (Fig.4), the average modulus of elasticity decreased from 1230 MPa (when panels were made of 2 scantlings) to 1055 MPa (when panels were made of 6 scantlings), while the average modulus of elasticity of the used scantlings decreased from 1225 MPa to 1017 MPa. It was determined (Fig. 4, a) that in such case the modulus of elasticity of the panels is higher approximately by 7 % with respect to the average modulus of elasticity of the used scantlings. As in the aforementioned cases, it was obtained that the damping coefficient of the panels was up to 30 % lower in comparison to the average damping coefficient of the scantlings forming them. Fig. 4b demonstrates that the average damping coefficient of the second-type panels varied from 0.026 to 0.030, and the one of scantlings – from 0.031 to 0.033.



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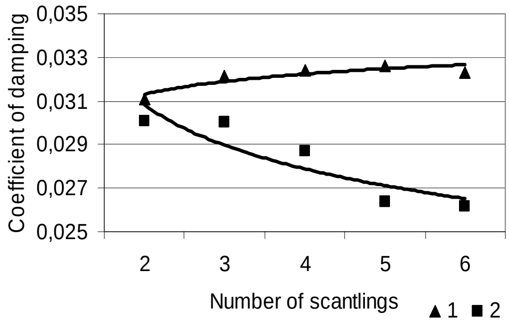


b

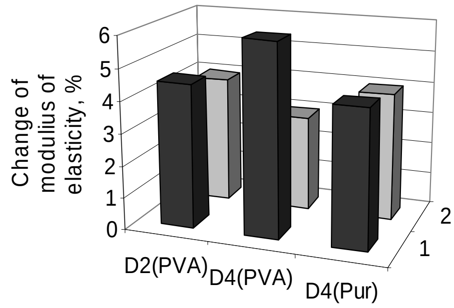
Fig. 4. Consistent patterns of varying average modulus of elasticity (a) and damping coefficient (b) of oak wood scantlings, and of the first-type panels made of them (T_{acr21}, T_{acr22}, T_{acr23}): 1 – for scantlings, 2 – for panels

Analogous results were obtained by gluing panels of other types and by using adhesives of others brands.

It was determined that using adhesives of different brands, the modulus of elasticity of panels altered up to 8 %, and damping coefficient - up to 30 %. The results of the research are presented in Fig. 5.

Three types of panels were also used for assessing the impact of quantity of gluing joints. Panel dimensions were $980\times500\times36$ mm, density – 660-730 kg/m^3, and their humidity was in the range of 9.2-10.3 %. The first-type panels were made of 5 scantlings (they are conditionally marked T1, T2 and T3), the second type – of 8 scantlings (T4, T5 and T6), and the third type – of 11 scantlings (T7, T8 and T9). The scantlings width of the first type panels was 100 mm, of the second - 63 mm, and of the third - 46 mm. The first vibration modes of the panels along grain are shown in Fig. 6. It indicates that the first modes of the panels along grain are of similar shape. However, their frequencies and amplitudes are different. With the increasing number of scantlings in the panel, oscillations frequency increased by about 7 %, and oscillations amplitude decreased by nearly 35 %.

It was estimated that with an increase in the number of gluing joints and with a decrease of the width of scantlings in the panel, the modulus of elasticity of the panel in both cases, across and along grain, increased by approximately 8 % (the average modulus of elasticity of across grain increased respectively from 806 MPa to 1014 MPa, and along grain – from 10155 MPa to 12271 MPa).



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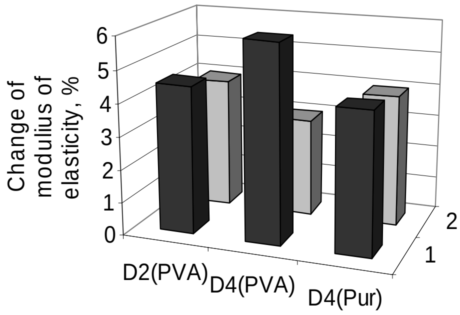

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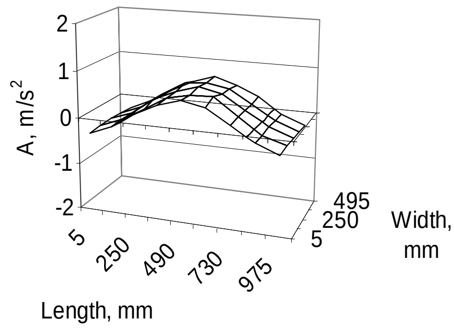
Fig. 5. Consistent patterns of varying average modulus of elasticity (a) and damping coefficient (b) when using adhesives of different brands: 1 – along fiber; 2 – across fiber



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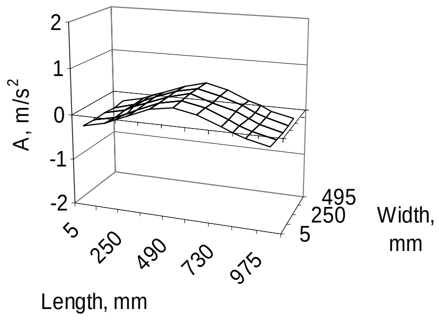

b

Fig. 6. First vibration modes of glued-up panels along grain: a – panel of 5 scantlings (f = 152.2 Hz); b – panel of 11 scantlings (f = 159.6 Hz)

No significant variation dependence between the number of scantlings in the panels and the damping coefficient of the panel was observed by analyzing amplitude-frequency characteristics of the panels. In some cases the damping coefficient changed by up to 30 % (when the shield was made of 8-10 scantlings).

In the final analysis, after evaluating various factors, it was determined that the modulus of elasticity of the panel was higher by roughly 10 %, and the damping coefficient – up to 40 % lower in comparison to the respective parameters of the used scantlings.

Thus, elastic plastic properties of a glued-up panel, and at the same time its behavior in the zone of dynamic loads will depend not only on the properties of adhesive and scantlings being used, but also on their geometric parameters and the number of sticking joints. Application of the presented research methodology enables fabrication of a panel with required parameters.

Conclusions

1. It was determined that when the glued-up panel was glued with a polyvinyl-acetate-resin-based adhesive of categories D2 and D4 as well as with polyurethane adhesive of category D4, the modulus of elasticity of the oak wood panel increased by up to 10 % and damping coefficient decreased by up to 40 % in comparison to the respective parameters of scantlings forming them.
2. Obtained results indicate that depending on the type of applied adhesive, the modulus of elasticity of the panel changed approximately by 2 %, and the damping coefficient - up to 10 %.
3. Research revealed that scantling arrangement order in the panel does not influence panel parameters. They depended only on the modulus of elasticity of scantlings, value of damping coefficient as well as on the brand of applied adhesive.
4. It was obtained that with a decrease of scantlings width, and with an increase in the number of sticking joints (scantlings) in the panel, their modulus of elasticity increased by approximately 6 %, and vibration amplitude decreased by approximately 35 %.
5. Performed investigation demonstrated that under various factors of gluing, the modulus of elasticity of the panel did not vary by more than 10 %, and the damping coefficient - 40 %.

References

[1] **Kasal B., Heudusche A.** Radial Reinforcement of Curved Glue Laminated Wood Beams with Composite Materials. Forest Products Journal 54 (1) 2004: pp. 74 – 79.

[2] **Cai Z., Ross R. J., Hunt M. O., Soltis L. A.** Plot Study to Examine Use of Transverse Vibration Nondestructive Evaluation for Assessing Floor Systems. Forest Products Journal 52 (1) 2002: pp. 89 – 93.

[3] **Soda S.** Role of Viscous Damping in Nonlinear Vibration of Buildings Exposed to Intense Ground Motion. Journal of Wind Engineering and Industrial Aerodynamics 59 (2-3) 1996: pp. 247 – 264.

[4] **Molin N. E., Lindgren L. E., Jansson V. E.** Parameters of Violin Plates and their Influence on the Plate Modes. Journal Acoustical Society America 83 (1) 1988: pp.281 – 291.

[5] **Ramazan K.** The Strength of Press-Glued and Screw-Glued Wood-Plywood Joints. Holz Roh- und Werkstoff 61 (4) 2003: pp269 – 272.

[6] **Feligioni L., Lavisci P., Duchanois G., De Ciechi M., Spinelli P.** Influence of Glue Rheology and Joint Thickness on the Strength of Bonded-in Rods. Holz Roh- und Werkstoff 61 (4) 2003: pp 281 – 287.

[7] **Pizzo B., Lavisci P., Misani C., Triboult P.** The Compatibility of Structural Adhesives whit Wood. Holz Roh- und Werkstoff 61 (4) 2003: pp 288 – 290

[8] **Molin N. E., Tinnsten M., Wiklund U., Jansson V.** FEM – Analysis of an Orthotropic Shell to Determine Material Parameters of Wood and Vibration Modes of Violin Plates. STL – QPSR 4 1984: pp. 11 – 37.

[9] **Carlsson P, Tinnsten M. A.** Distributed Computing System Tested with Collaborative Optimization Routines on a Violin Top. 1987: pp. 1 – 10.

[10] **Timoshenko S., Young D. H., Weaver W. jr.** Vibration problems in engineering. Moscow. Mashinostroenie, 1985: p. 472.

[11] **Albrektas D., Vobolis J.** Evaluation of Mechanical Parameters and Quality of Solid Wood Panel by Vibration. Proceedings of the 5th International Conference Vibroengineering – 2004 ISSN 1392 – 8716 2004: pp. 49 – 54.

[12] **Broch J. T.** Mechanical Vibrations and Shock Measurements. Grostrum. K. Larsen and Son, 1984: 370 p.