526. Testing the effect of transverse resonant vibrations on wood impregnation

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Abstract. Seeking to expand the range of operation and durability of wood articles, in many cases they must be impregnated with relevant materials. The process consumes a lot of time. Different technologies are applied for modification of depth and speed of impregnation. A method of vibrational wood impregnation is presented in this paper. It was determined that the transverse vibrations of scantlings in water are analogous to those in air, only the frequencies are different by 1.5 times. This study reveals that the amplitudes of vibrations in water and in air are close to each other, while the coefficient of damping in water is larger by 50 %. It is demonstrated that in many cases the scantlings undergoing resonant vibrations in the same time absorb up to 30 % more water than in the case of non-vibrant scantlings. The results of these investigations may be applied in wood impregnation industry.

Keywords: resonant vibrations, wooden scantlings, vibrations mode, vibrations in water, coefficient of damping.

Introduction

Being one of the widely used materials, wood has a few disadvantages that include low resistance to fire, harmful insects, physical, mechanical and other factors [1–3]. When aiming to expand application areas of wood products and to extend their lifetime, timber products undergo impregnation with respective materials that tend to be water soluble on a frequent basis and show physical properties similar to water properties.

The impregnation of dry wood involves immersing it in liquid or covering it with liquid. This is how liquid penetrates into deeper layers by being subjected to capillary forces. If there is a short period of time, impregnation materials fail to penetrate deeply into wood, therefore, a longer period of time is needed for achieving deep impregnation.

Various technologies are applied in pursue of increasing the depth of liquid penetration and reducing the impregnation time. Prior to carrying out impregnation, wood undergoes heating as a rule or it is kept at pressures lower than atmospheric. In some cases high pressure liquid is used for wood impregnation [1–3], which requires sophisticated and expensive equipment as well as high energy consumption.

It is a well-known fact that vibrations are used for impregnating nonwoven textile materials [4]. Latex-impregnated materials show better physical and mechanical properties. In addition, when using vibrations, impregnated nonwoven materials tend to better transmit gases and liquids.

Vibrations are also used for dying wood [5], since a vibrant assortment allows dyes to penetrate deeper into it. The method has one disadvantage; only a small amount of dyes remains on the top layer. Meanwhile, low material consumption appears to be one of the biggest advantages here.

The method of resonant vibrations is applied to test wood products and textile fabrics. By evaluating amplitude-frequency characteristics, dynamic rigidity and coefficient of damping can be determined [6–8].

The main objective of this work is to assess how transverse resonant vibrations of wood scantlings influence wood impregnation.

Testing methodology and equipment

The testing process of wood scantlings involves an original stand and a measuring instrument. Figure 1 shows the scheme of measurement setup.

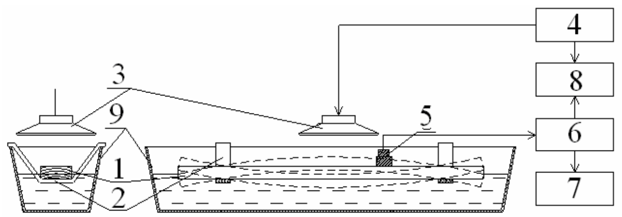


Fig. 1. The scheme of measuring setup: 1 – wood assortment and its bending; 2 – elastic elements; 3 – acoustic vibrator; 4 – vibration generator; 5 – vibration detector; 6 – measuring instrument; 7 – oscilloscope; 8 – phase meter; 9 – water container

A wood scantling being on test (1) is loosely attached to the elastic elements (rubber strips) (2). The acoustic vibrator (3) controlled by the vibration generator (4) excites resonant vibrations in the scantling (1). The vibration detector (5) senses these vibrations and the measuring instrument (6) measures their amplitude. The phase meter (8) measures the signal phase of the vibration detector with regard to the signal phase of the generator. The oscilloscope (7) screen records the shape of vibration signal.

The equation below is provided in relation to free vibrations in the wood scantling, based on the bending theory:

$$\rho S \frac{\partial^2 z}{\partial t^2} + \frac{\partial^2}{\partial x^2}\left(EI \frac{\partial^2 z}{\partial x^2} \right) = 0\,; \qquad (1)$$

ρ – density of wood scantling; S – cross-section area; E – modulus of elasticity (Young's modulus); I – moment of inertia of cross-section.

The following equation is used for calculating the value of transverse vibration frequencies:

$$f = \frac{A}{2\pi} \sqrt{\frac{EI}{\rho S l^4}}\,; \qquad (2)$$

A – coefficient depending on wood scantling attachment and vibration mode; l – beam length.

After establishing the resonant frequency of the scantling f_o, as well as other two frequencies f_1 and f_2 next to which the resonant amplitude tends to decrease by $\sqrt{2}$ times, the coefficient of damping is calculated in the following way [9]:

$$tg\delta \approx \frac{f_2 - f_1}{f_o}; \qquad (3)$$

$tg\delta$ – loss angle tangent of wood.

There is approximate correspondence between the “attachment” method and the freely vibrating scantling (the first mode of vibrations A = 22.4 in the present case).

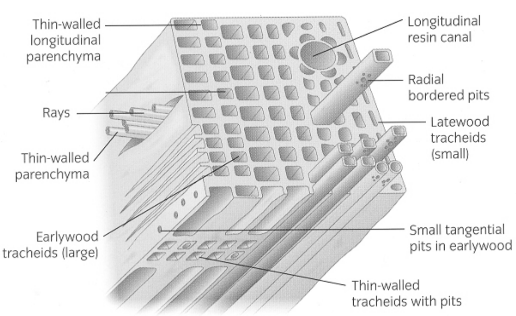
In order to ensure the full contact between the scantling surface and water, the container is filled with water (roughly 1/3 of scantling thickness is immersed).

The description of the measurement process is provided below.

The wood scantling is attached to the elastic elements (2), its transverse vibrations are excited and the resonant frequency corresponding to the first mode is set.

The scantling undergoes vibration in water next to the resonant frequency for a certain period of time (4 hours), which allows determining the quantity of absorbed water. Subsequently, the established quantity is compared to the quantity of absorbed water specific to the scantling that does not undergo vibration and obtained in advance during the same period of time.

The wood scantling structure incorporates a stiff and single-part frame, which consists of tightly-joined hollow elements that happen to be thin-wall tubes of various lengths in general (Figure 2).



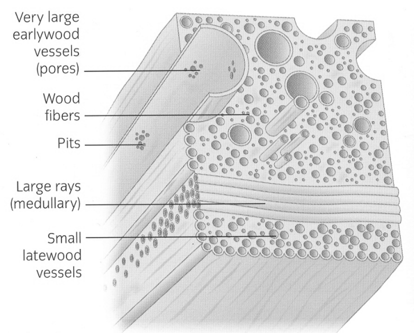


Fig. 2. The macrostructure scheme for coniferous (a) and deciduous (b) wood [10]

These hollow elements are composed of cells, can be filled with air or water and are capillaries in terms of their structure. Cell walls contain pores that allow liquid to flow into and out from the cell, which results in a general branch system of water paths. Since the main channels are directed along the wood fiber, there is better water absorption and removal towards this direction.

Cell cavities accumulate so-called free (capillary) moisture.

When bending the beam-shaped wood scantling, cells on its upper part undergo stretching and those on the lower part are under compression. Water contained in cells is forced to flow both along and across the space. Differences in the deformation of the upper and lower parts lead to a different path of water flow (including its quantity) in them.

When the scantling is vibrating in transverse direction, wood cells undergo compression and expansion (which is analogous to the operation of membrane or diaphragm water pump) on a repeated basis. When the scantling surface interacts with water, wood cells undergo expansion and compression with water being sucked and removed respectively. Changes in the scantling deformation mean that this process will be different during the separate vibration semi-periods.

It becomes evident that the transversal vibrations of the scantling will influence water absorption in wood.

Tests involved 80 pieces of birch wood scantlings cut along the fiber with the following dimensions: $450 \times 55 \times 15$ mm. In addition, wood moisture (9 – 10.5 %) together with density (555 – 690 kg/m^3) was determined.

The scantlings were divided into two groups (I and II) with 40 pieces in each. Group II had scantling ends covered with water resistant glue (PVA3), which allowed assessing water absorption in wood across and along the fiber (group I), as well as only across the fiber (group II).

The scantlings of these groups (I and II) were divided into two subgroups with 20 pieces in each: subgroups I.I and I.II with scantlings without glue and subgroups II.I and II.II with glue-covered ends. The subgroups had similar scantling densities and prevailing fiber direction.

Subsequently, the container (9) was filled with water where approximately 1/3 of scantling thickness was submerged. Scantlings belonging to subgroups I.I and II.I underwent impregnation for 4 hours without vibration application, whereas scantlings in subgroups I.II and II.II underwent the same process with vibration application.

Test Results

It was found that scantlings had the resonant frequency of the first mode ranging between 345 and 407 Hz [6, 7]. Figure 3 shows the first mode shape of the scantling with vibration occurring in air.

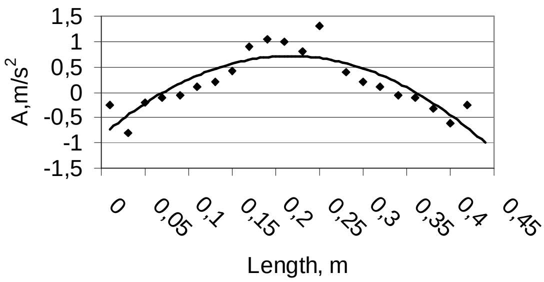


Fig. 3. The first mode shape of the scantling vibrating in air

Calculations carried out in relation to vibrations of a deformed isotropic beam allowed determining the modulus of elasticity of scantlings (12000 – 16600 MPa) together with the coefficient of damping (0,010 – 0,015) [6, 7].

Subsequently, the mode shape of scantlings vibrating in water underwent evaluation (Figure 4).

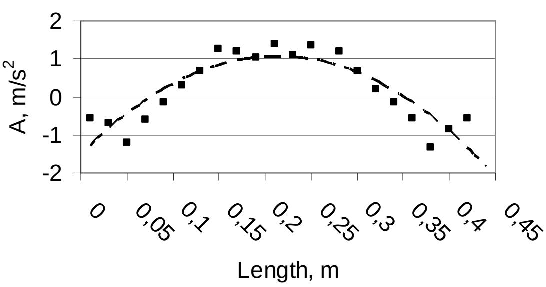


Fig. 4. The mode shape of the scantling vibrating in water

It can be observed (Figures 3 and 4) that there were analogous modes of scantling vibration in air and water. It was determined that the resonant frequency of scantlings tended to be significantly lower in water (210 – 250 Hz). Furthermore, similar vibration amplitudes were established in both cases. There were significant changes in the coefficient of damping of scantlings with an increase in 60 % (0,013 – 0,017) in water.

During the impregnation process, the change in the resonant frequency of scantling vibrations was recorded (Figure 5).

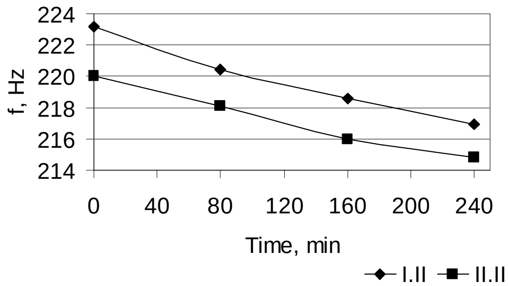


Fig. 5. The dependency between the average change in the resonant frequency of scantlings and the impregnation duration: I.II means a mixed fiber direction, meanwhile II.II indicates across the fiber

Tests revealed that with scantlings in subgroup I.II undergoing impregnation, their frequency tended to decrease from 223 to 217 Hz (2,7 %) on average, whereas in the case of subgroup II.II the number reached 220 - 215 Hz (2,3 %). In the first and second case the frequency alteration in separate scantlings was 4 – 11 Hz and 2 – 7 Hz respectively.

Figure 6 provides the alteration law of the coefficient of damping.

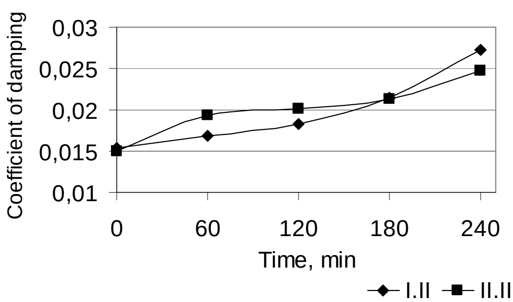


Fig. 6. The dependency between the average coefficient of damping of scantlings and the impregnation duration: I.II means a mixed fiber direction, meanwhile II.II indicates across the fiber

It was determined that the average coefficient of damping of scantlings belonging to subgroup I.II varied from 0,015 to 0,027, meanwhile in the case of subgroup II.II it ranged from 0,015 to 0,025. These alterations constituted 80 and 67 % respectively.

It can be observed that when restricting water access to scantling ends (along the fiber), there are marginal changes in their resonant frequency and coefficient of damping within the same period of time.

Figure 7 shows water quantities that passed through scantlings in different fiber directions.

It can be observed (Figure 7) that transversal vibrations have a considerable effect on contained water quantity. In the case of scantlings in group I (along and across the fiber) 7 – 19 g of water entered through scantlings without vibration application, meanwhile scantlings with vibration application contained 5 – 38 g of water. This difference continued to change within the range of 15 – 50 %. After restricting water access along the fiber, water quantity was 7 – 18 g. It was established that in the present case the difference of water quantity between scantlings with vibration application and those without vibration application was up to 29 %.

In addition, it was found that there were significant changes in the resonant frequency and coefficient of damping of scantlings with larger water quantities.

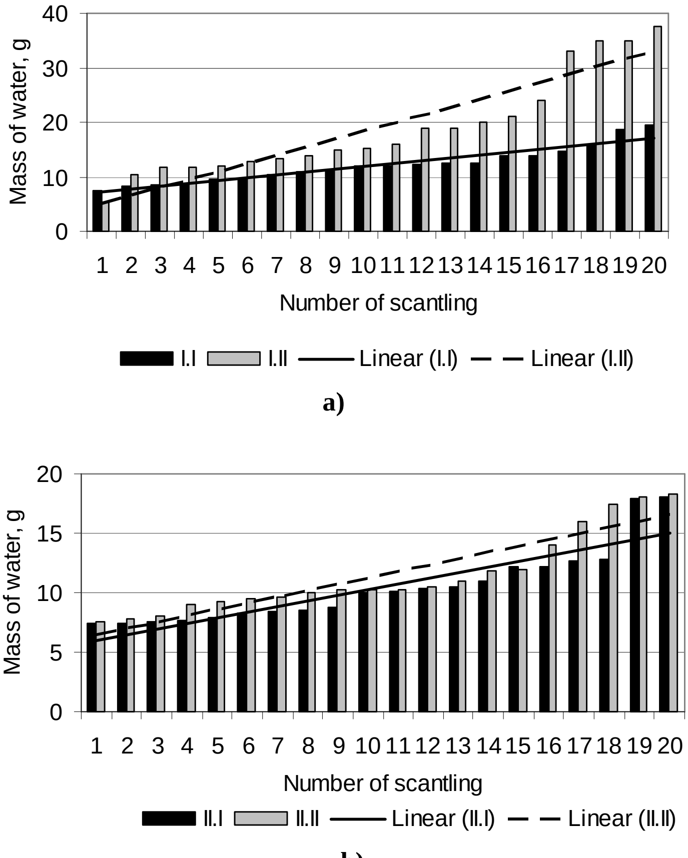


Fig. 7. The comparison of water quantities contained in scantlings: (a) – along and across the fiber; (b) – across the fiber; I.I and II.I – scantlings without vibration application, I.II and II.II – scantlings with vibration application

Figure 8 illustrates average water quantities contained in scantlings.

It can be observed (Figure 8) that scantlings undergoing vibration tend to contain more water during the same period of time: tests indicate that a larger quantity of water reaching up to 36 % entered through scantlings with vibration application in a mixed fiber direction. As soon as water access was restricted along the fiber, the difference constituted about 9 %.

Since transversal vibrations contribute to short term impregnation and low energy consumption, this method proves to be useful for wood modification.

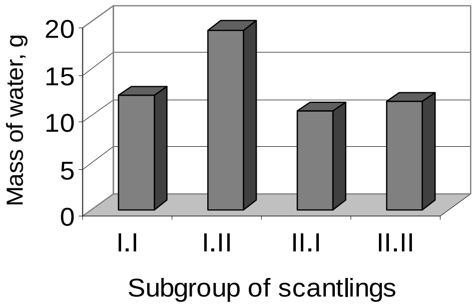


Fig. 8. The average water quantity in scantlings: I.I – across and along the fiber, without vibration application, I.II – with vibration application, II.I – across the fiber, without vibration application, II.II – with vibration application

Conclusions

1. It was established that when scantlings are exposed to water, they vibrate in modes that are identical to those observed in air.
2. It was found that the vibration frequency of scantlings tends to decrease by approximately 40 % in water and the amplitudes in water and air share similar values.
3. It was determined that there is a decrease in the resonant frequency of scantlings and an increase in the coefficient of damping in proportion to the contained water quantity.
4. Tests demonstrated that within the same period of time scantlings undergoing vibration hold twice as much water when it enters through in a mixed direction and 1.3 times more water when it passes through across the fiber.
5. Testing revealed that the coefficient of damping of impregnated scantlings exceeds the one of dry scantlings by 10 – 60 %.

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