SPECIFIC DYNAMIC SHEAR MODULUS OF DRILLED BEECH WOOD

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In this research, specific dynamic shear moduli in plane with LR and LT surface of 22 rectangular clear beams of beech wood (*Fagus orientalis*) were evaluated in “free flexural vibration of a free-free bar” method with and without the presence of drilled holes on the tangential surface. The drilling was done exactly at the middle of the bar, on the node of the 2nd mode of vibration. Stepwise hole widening from zero to 3, 5, 8, and 10 mm, visible on two opposite tangential surfaces were used. Beech timbers were converted to nominal dimensions of 20×20×360 mm R×T×L. After measuring the dimensions and calculating the density (ρ) of the specimens, for both radial and tangential impacts of hammer in which the beam was vibrated in LT and LR plane, respectively, two specific shear moduli (specific GLR and specific GLT) were evaluated in Timoshenko beam theory, considering the three initial modes of vibration. When the bar was excited from its tangential surface by a percussion (vibrated in LR plane), stepwise drilling raised the estimated value for specific shear modulus in LR plane (Specific GLR). However, in LT vibrations, the specific GLT remained statistically constant. It is clear that the specific shear moduli as material property are not affected by artificial manipulation, but the responses of the bars would be affected. So the obtained result has been discussed due to neutral axis related to the hole localization. The finding of this paper may be used as an indicator for recognition of a hidden hole, perpendicular to the growth rings.

Keywords: Defect; Drill; Flexural, Nondestructive; Specific shear modulus; Vibration

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INTRODUCTION

Free-free flexural vibration tests can be used to accurately determine the elastic constants of wooden beams such as Young’s modulus and the shear modulus (Hearmon 1958). In an orthotropic material, there are different values for shear modulus depending on the surface. In the case of wood, this parameter varies in each orthotropic plane of LT, LR, and RT corresponding to radial, tangential, and cross section, respectively. Several hypotheses related to the elastic symmetry of wood were developed (Bucur 2003). It is noted that triclinic symmetry is the most complex, which allows the determination of 21constants (Bucur 2003).

In addition to standard tests, non-destructive methods have recently been used to evaluate the mechanical parameters and their behaviors. In this field, vibration-based techniques are widely known as fast, reliable, and inexpensive procedures for crack identification (Loutridis 2005). Vibration techniques have been used in some non-destructive evaluation applications for determining the shear modulus (Bodig and Jayne 1982; Brancheriau and Bailleres 2002; Cho 2007; Divos and Tanaka 2005). There are certain advantages to using the vibration approach to determine modulus over the static methods. Meanwhile, the time for a vibration test is shorter than that for the alternative static test (Chui 1989). Flexural free-free beam vibration technique has been widely used for estimating shear modulus of wood, while modern instrumentation enables this method to easily be applied (Cho 2007).

In recent years, several scientists determined and compared static and dynamic shear modulus, and they found good correlation between them (Perstorper 1994; Divos and Tanaka 2005; Liang and Fu 2007; Nzokou *et al.* 2006; Cho 2007; Yang *et al.* 2002).

A beam may be vibrated parallel to LR and LT planes resembling the flexural, transverse vibration and using related theories, the longitudinal modulus and the shear modulus would be obtained from modal frequencies, in both cases, almost equal to each other. In the flexural vibration test, equations of modulus of elasticity evaluation are applied to clear sound woods. When a defect reduces the homogeneity, this equality may be washed out (Roohnia 2010).

The defects of wood were regularly investigated in recent decades. Roohnia *et al.* (2006) evaluated the specific modulus of elasticity and shear modulus (radial and tangential) across the *Cupressus arizonica* logs. In their research, free vibration based on free-free bar was used. The authors claimed that specific MOE decreases significantly from pith to bark. Roohnia *et al.* (2009) mentioned that the existence of crack in wooden beam in free vibration method affects the correlation between radial and tangential shear modulus and decreases this correlation significantly. Caddemi and Morassi (2006) detected the cracks in elastic beams by static measurements. Beall (2000) tried the subsurface sensing of wood and wood-based materials. This method has been defined as any technique that acquires properties of the materials in a non-invasive manner and therefore that will be considered similar to nondestructive evaluations. Brancheriau and Bailleres (2002), in a theoretical review, studied the natural vibration analysis of clear wooden beams. In another research study, Brancheriau and Bailleres (2003) highlighted the possibility of developing a high performance grading process based on the analysis of acoustic vibrations in the frequency domain. The uniqueness of the introduced method was the direct use of the spectrum as predictive variables to estimate the modulus of elasticity and modulus of rupture. Divos *et al.* (2001) presented an investigation concerning the suitability of a special amplitude-technique for wood. The study included the examination of the acoustic coupling between the wood and the signal generator, the damping of the signal in wood, the effect of sloping grain, and the equipment's capacity in detecting artificial defects (sawn notches). The results revealed that a uniform wave-front develops at a distance of 60 cm from the signal source, that the amplitude decays exponentially with distance, and that the amplitude is a considerably more sensitive defect indicator than propagation velocity. Meinlschmidt (2005) used a thermographic camera to detect defects in wood and wood-based materials. Vatul'yan and Solov'ey (2004) described a method for determining the type and size of a defect at the boundary of two elastic bodies. The proposed method was based on the difference in the character of the stressed deformed state inside a body in the near vicinity of a defect depending on the type of a defect and its presence. The method relied on the solution of a number of direct boundary-value problems (by the method of finite elements) and inverse problems (by the method of boundary integral equations). Roohnia *et al.* (2009) studied the effects of end longitudinal cracks on elastic parameters of poplar wooden rectangular bars. Their case study revealed that if longitudinal specific modulus of elasticity evaluated from both LR and LT flexural vibrations were almost equal and G_{LR} was slightly larger than G_{LT}, the user could be confident enough to consider the specimen without any severe longitudinal cracks. Roohnia *et al.* also monitored the values of modulus of elasticity and modal frequency shifts after drilling similar holes on the beams (2011a, b). Continuing the above mentioned research on wood defects recognition using nondestructive tests, the effect of the drilled hole as the artificial defect on the specific shear modulus evaluations, accessible from two flexural vibrations in plane with LR and LT surfaces has been studied in this approach.

MATERIALS AND METHODS

Samples of *Fagus orientalis* were used in this research. According to ISO 3129 international standard (1975), 30 rectangular and visually clear wooden bars were prepared. The specimens were cut to their final nominal dimensions of 20×20×360 mm, R×T×L, and then conditioned at 21°C and 65 percent relative humidity for two weeks until their moisture content was stabilized. At the middle point of the length, on the tangential surface in the radial direction, a hole with a diameter of 3 mm was drilled and its diameter made wider gradually to 5, 8, and 10 mm. All applied drilled holes were visible with a similar appearance on both tangential surfaces (Fig. 1).

Fig. 1. Drilling a hole at the middle of the beams on the tangential surface in radial direction.

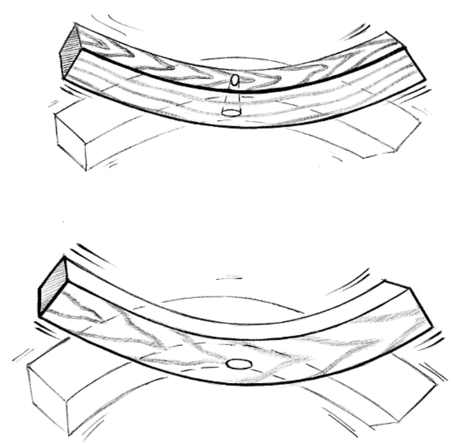

Fig. 2. Position of the artificial drillings related to neutral axis for LR (up) and LT (lower) flexural vibrations.

Before and after creation of holes and computation of the mass reduction of the bars due to the drilling, the free flexural vibration test was performed on all free-free bars and placed on soft thin elastic rubbers. The use of Individual impacts either on radial or tangential surfaces excited the bar to vibrate in LT and LR planes, respectively (Fig. 2). The location of impacts and the location of the recording microphone were located at the opposite ends of the beams. Vibrations were recorded as audio files at a project rate of 44100 Hz. Every selected and saved acquisition sound file contained 14000 to 18000 points depending on the attenuation through the time that was less than a second. After reading the audio files at the same project rates, the three initial modes of vibration were obtained from a magnitude of Fourier Transform spectrum in MATLAB v.7.1 (Fig. 3). Two shear moduli, G_{LT} and G_{LR}, values were evaluated through Timoshenko beam theory (Bordonne 1989, Brancheriau 2003, and Roohnia 2009) and after ensuring the specimen was healthy, trends of Timoshenko beam theory with the highest correlation coefficients were accepted and selected before creation of drilled holes. Then the specific shear moduli ($Pa.m^3/Kg$) were calculated directly from the ratio of shear modulus (Pa) by stabilized density (Kg/m^3).

The scatter plots of specific dynamic shear modulus values out of LR and LT flexural vibrations were developed, and the correlation coefficients of their proper trend line were calculated. Then the observed correlations were certified through statistical methods of Pearson bivariate correlation test for the significance of correlation, analysis of variances test for the effect of stepwise drilling and widening a hole on the obtained shear modulus values followed by the Duncan test for categorizing the values to the homogeneous subsets.

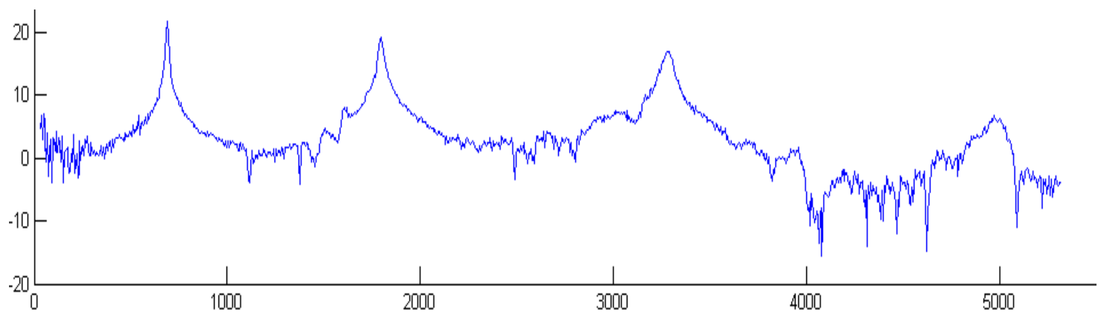

Fig. 3. Three initial modes of vibration shown in magnitude of a Fourier Transform. Y axis corresponding to amplitude in dB and X axis the frequency in Hz

RESULTS AND ANALYSES

Free flexural vibration on a free-free bar was performed to evaluate the shear modulus values in 30 clear sound samples. Based on the Timoshenko theory, considering the most efficient evaluations using three initial modal frequencies, 22 samples out of 30 were admitted as the clearest and the most homogeneous ones and taken into the account for drilling artificial holes and further experiments.

Stepwise drilling had no significant effect on the efficiency of Timoshenko beam theory application until the end of the third step of widening the holes (5 mm). After the fourth (8 mm) and the fifth step (10 mm), the related correlation coefficients both in LR and LT vibrations reduced significantly but similarly. Though these evaluations in defected beams were not as strong as that of clear specimens, the comparison between results of LR and LT vibrations, even after the fourth step, was admitted to stay valid.

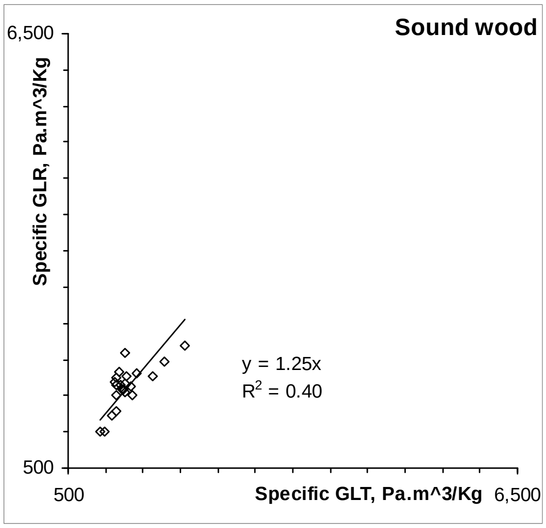

Fig. 4. Specific shear moduli values of clear sound specimens

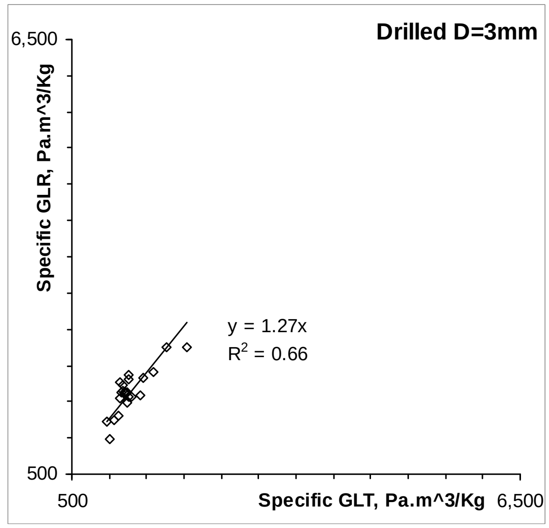

Fig. 5. Specific shear moduli of specimens containing a 3 mm wide drilled hole on their tangential surface

Figure 4 shows the correlation of the specific shear moduli values obtained in vibration tests at LR and LT plans. After widening the holes, the specific shear moduli values out of LR vibration increased step by step, while in the LT vibration test the values remained considerably constant (Figs. 6 to 8). The scales of the vertical and horizontal axis remained constant within the figures to enable the monitoring capability of value shifts after drillings. The observed effect of stepwise widening of drilled holes on LR vibration to evaluate the specific shear modulus was certified in analyses of variances followed by Duncan multiple comparison statistical tests. There was no clear and significant effect on obtained results of LT vibration (Tables 1 and 2).

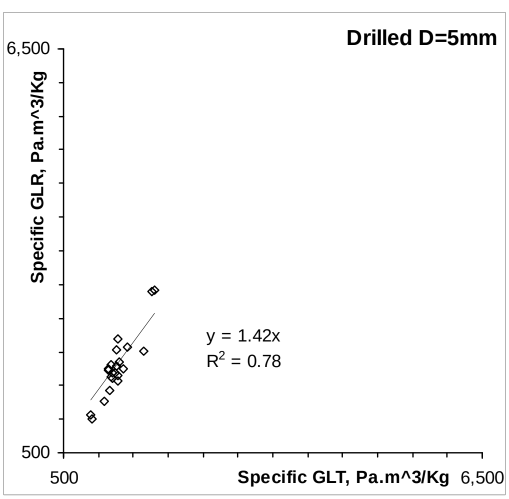

Fig. 6. Specific shear moduli values of specimens containing a 5mm wide drilled hole on their tangential surface

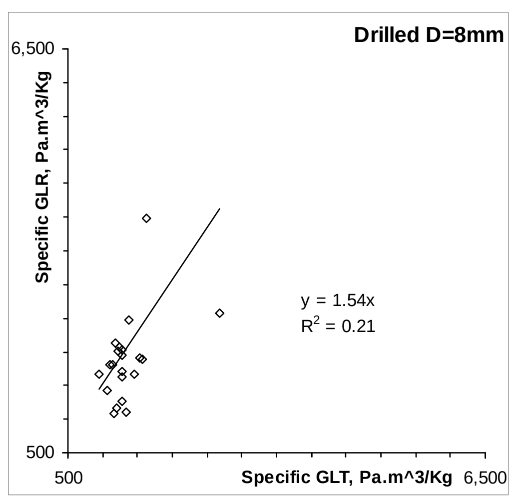

Fig. 7. Specific shear moduli values of specimens containing a 8mm wide drilled hole on their tangential surface

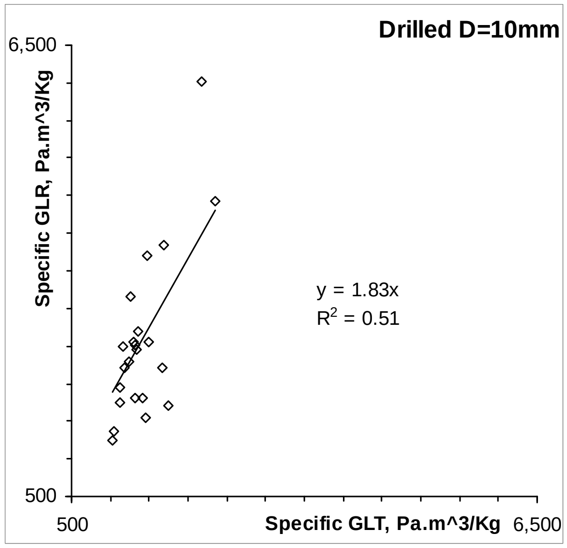

Fig. 8. Specific shear moduli values of specimens containing a 10 mm wide drilled hole on their tangential surface

CONCLUSION AND DISCUSSION

The objective of this research was to find the effect of drilling on specific shear modulus. Specific shear modulus is a material property that does not change after artificial manipulations of the bar. However, in this study, this property has been specifically defined as the response of a bar, although the response of the bar would be affected. At first look, it could be seen that the mass loss in the drilled beams must affect the calculations not the response of the bar, but this assumption is rejected. The mass reduction must affect both the LR and LT vibrations, whereas only the LR vibration was changed. Meanwhile the mass reduction amounts were not statistically significant in relation to the whole mass of the specimens. So the main effect would be definitely brought from the artificial holes.

Stepwise hole widening affects the LR vibration in evaluation of the specific shear modulus, while that of LT vibration remains constant. It is clear and simply justifiable. The reason is found in the concept of neutral axis of bending. When the beam vibrates transversely, temporarily the bending occurs. There is no bending stress on the neutral axis so there would not be any important effect from this axis to the flexural vibration properties. As the bar is vibrated in LT plane, the artificial drilled hole mostly lies on the neutral axis. However it is predicted in greater diameters of holes that even the LT vibration may be affected. In LR vibration the drilled hole elongated across the height of the bended bar. It means that some parts of the defined artificial defect are located in some distances from the neutral axis that can influence the bending stress and flexural vibration properties.

It was certified that there is a difference between two series of evaluations of specific shear moduli through LT and LR vibrations in sound beams. So the introduced differences might be a potential indicator of defect. The greater differences between shear modulus evaluations of a proper bar may indicate the greater defect, *i.e.* hole.

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