Vibrational measurement of shear modulus and damping of wood: An application of the Vybris-Torsion device

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Introduction

The shear properties of wood are essential mechanical properties. From an engineering point of view, it might be used for evaluating failure criteria, focusing in particular on its strength properties. In a cultural aspect, it is a factor for the sound quality of wood. It is proved that the G_{LT} shear modulus plays an essential role in the soundboard of string instruments (Viala et al. 2018). E_L/G_{LT} ratio also controls a low-pass filter for suppressing some high-frequency noises that make the sound from wood distinguished from other material (Nozaki et al. 1988). While the order of bending vibration mode raising, the shear deformation increases. As a result, the apparent E_L value also decreases (E/G). In the meantime, the tendency of damping by internal friction (tan δ) could be increased (Ono 1980; Obataya et al. 2000). Furthermore, for different instruments, the criteria for determining wood material quality is different (Brémaud 2012). For example, high damping during the high frequency vibrations and low damping in the low-frequency range are suitable for the violin, while the specific elastic modulus is more important to evaluate the wood quality for a piano (Tatemiti 1960). The sub-structure of the wood cell, especially the secondary cell wall (S2) and its microfibril angle (MFA), influences the vibrational properties, including the elastic modulus, and damping, in axial and shear (Obataya et al. 2000). In some cases, when a wood species contains many secondary metabolites (extractives), or has a great deviation of the grain angle (GA) according to the longitudinal direction, its elastic (shearing and axial) and damping properties are also affected (Brémaud et al. 2010; Minato et al. 2010). As axial bending vibrational properties are primarily affected by MFA, while the shear vibrational properties are rather influenced by the cell-wall matrix, measuring both axial and shear properties on the same wood specimen should provide insight into the structure-chemistry-properties relationships. More generally, for evaluating the wood's quality, it is necessary to measure its anisotropic dynamic elastic modulus and damping. A compact device for the dynamic bending properties has been built in LMGC. In the present work, a new version for dynamic torsion properties was developed and tested. In order to evaluate the workability, we chose two species and compared with the literature data.

Materials and Method

Two wood species were used in the present article. One is *Acer pseudoplatanus* L. (sycamore maple, wavy maple), and the other one is *Picea abies* (L.) H. Karst (spruce). The nominal dimensions of the samples were 150 mm (longitudinal, L)×12.5 mm (radial, R, expressed as *a* later) ×1.75 mm (tangential, T, expressed as *b* later). They have been conditioned at 20±2℃ and 65±5%RH for more than three weeks in order to stabilize their damping properties (Brémaud and Gril 2020).

The device was designed in order to allow, on a same measuring bench, to switch easily from the bending vibrations, to the torsion vibrations. The set-up of the torsion device itself is given in Fig. 1. The mass moment of inertia (I_m) of the downer clamp (including two screws, and steel plates) was calculated, which is 2.81×10^{-6} kg·m². The span (S) from the upper clamp to the downer clamp is 80 mm. The calculation of the shear modulus (in the present case, G_{LT}) is then obtained by the acquisition of the natural torsional vibration frequency (f_t) and the following equation:

$$G = \frac{12\pi^2 f_t^2 S I_m}{Cab^3} \tag{1}$$

with C, a correcting factor for the rectangular cross section of the sample, calculated as (Ono 1980):

$$C = 1 - 0.6302/\left(\frac{a}{b}\right) \tag{2}$$

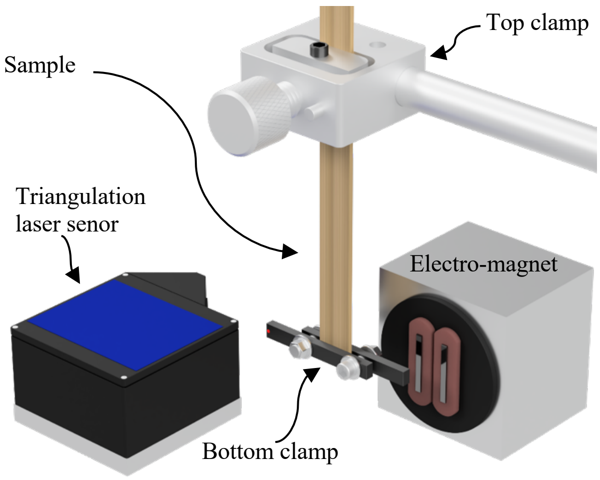

Fig. 1: The set-up of the Vybris-Torsion device. The fixed end is on the top, and the bottom clamp is sinusoidally rotated by means of an electro-magnet. On the left side is a triangulation laser sensor for the measurement of the rotation.

Results and Discussion

The longitudinal and shear modulus of 8 specimens for each species were obtained. The longitudinal dynamic elastic modulus (E_L') and damping (tan δ_L) were measured by the “classical” Vybris device (Brémaud 2006) in bending, and the frequency of the first mode of bending vibration (f^E) is listed in Tab. 1. Also, the shear modulus (G_{LT}'), the damping (by the half-power method on the bandwidth, Q^{-1}) and the natural torsion frequency (f^G) of each specimen are reported. The results show that the spruce had a lower damping value than wavy maple, both in bending (axial) and in shear. By comparing their elastic modulus, we could find that spruce had generally a larger axial modulus, but a lower shear modulus, than maple.

Compared with previous research on spruce and maple (Tatemiti 1960), all the data’s value shares a similar result compared with this forced triggering experiment at around 600 Hz. When comparing the *E’/G’* ratios (not listed in the Tab. 1), the result gives a low ratio on wavy maple (4.9 ~ 6.4) but a high ratio for spruce (6.6 ~ 10.5). This gives a relatively low value compared with those from Nozaki et al (1988) where their *E’/G’* values of spruce and maple were 17.8

and 8.6, respectively. The axial-to-shear ratios in damping (tan δ_G/tan δ_L) also appear in the lower range as compared to previous values (Carlier et al. 2018). This is currently being verified by testing more samples.

The correlation of tan δ_G/tan δ_L with *E'/G'*, which was described in the literature of (Obataya et al. 2000) (Fig. 2), shows that two species shared similar trends with ones from the literature. Therefore, we could determine the workability of the new Vybris-Torsion device, while more tests are still required.

Tab. 1 Results of two wood species for their elastic modulus and rigidity modulus tested by Vybris device

Wood Species	Values	Density (g/cm³)	Dynamic elastic modulus				Damping (×100)	
			E_L' (GPa)	f^E (Hz)	G_{LT}' (GPa)	f^G (Hz)	Bending	Shear
Wavy Maple *Acer pseudoplatanus* L.	Mean	0.54	7.56	293.48	1.37	58.17	1.09	1.53
	S.D.[c]	0.01	1.10	19.90	0.12	2.56	0.12	0.13
Spruce *Picea abies* (L.) H. Karst	Mean	0.45	9.17	352.09	1.12	51.54	0.85	1.39
	S.D.[c]	0.02	0.49	13.53	0.14	2.88	0.03	0.14

a. All the significant figures were trimmed down to 2 digits after the decimal separator
b. The specific gravity and elastic modulus were all measured under the condition of 20 ± 2 °C and 65 ± 5 % RH
c. Standard deviation. The values were trimmed down as the regular a

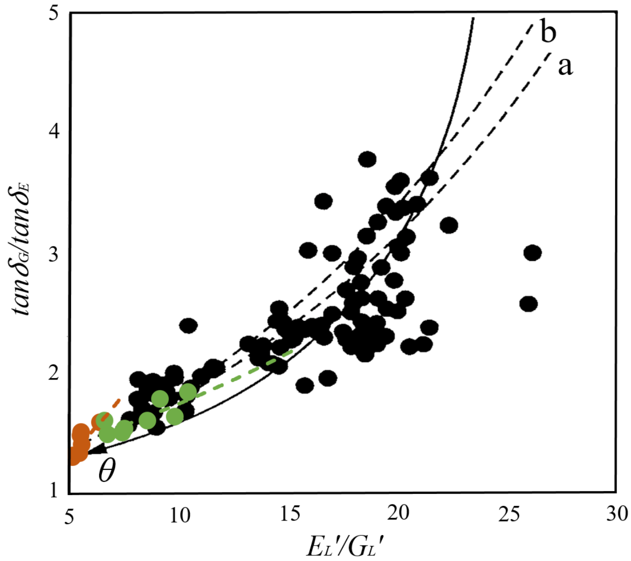

Fig. 2: A comparison of the present data with literature (Obataya et al. 2000, the figure has been revised) for the correlation of tan δ_G/tan δ_L and E_L'/G_L'. Black (literature data): the dots are the experimental values for spruce; (a) is the regression line for spruce; (b) is the regression line from 101 species; θ is the cell wall model developed in the literature. Color (present data): the orange dots correspond to wavy maple; the green dots to spruce.

Perspectives

During the first step of this work, the device was developed and several experimental factors have been tested. The new Vybris-Torsion device is now functional for conducting wide series of tests. The impact of the sample dimensions (that impacts the measuring frequency) and of boundary conditions (clamps) should be quantified. The preliminary results shown here suggest that the range of values of measured properties are realistic when compared with literature values. The next step, which is under realization, is the measurement of a wide sampling on which axial and shear moduli and damping previously measured by other methods (Carlier et al. 2018; Viala et al. 2018). This complete comparison will be presented in the final poster. In near future, this new device is intended to be used for evaluating the axial-to-shear anisotropy of figured woods (wavy, interlocked, etc) and to relate it with effects of local GA and of MFA.

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