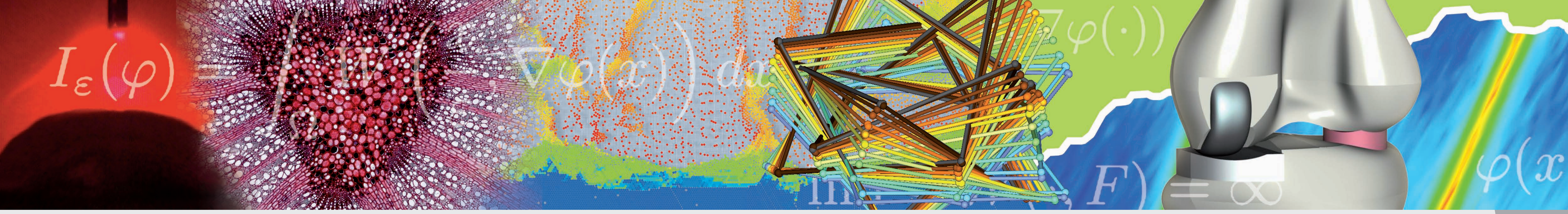

Vibrational measurement of shear modulus and damping of wood: An application of the Vybris-Torsion device

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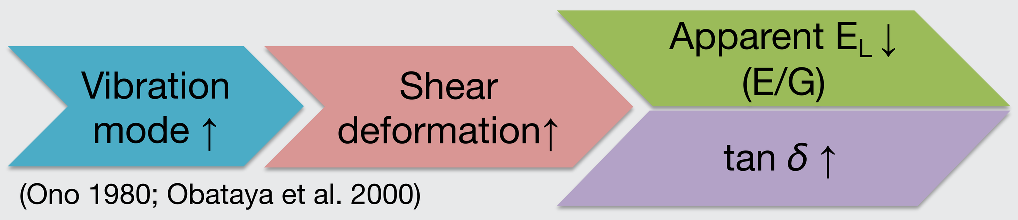
Introduction

Shear properties of wood are an important factor for the "sound quality" of wood, and are necessary for a more complete material description.

Parameters affecting sound

- E_L/G_{LT} ratio is like a low-pass filter for suppressing some high-frequency noises that make the sound of wood distinguishes itself from other materials (Nozaki et al. 1988)
- G_{LT} shear modulus plays an essential role in the soundboard of string instruments (Viala et al. 2018)
- Criteria for determining wood quality for instruments (Brémaud 2012):
  Violin: high damping of high-frequency vibrations and low damping in the low-frequency range
  Piano: high specific elastic modulus (Tatemiti 1960)



(Ono 1980; Obataya et al. 2000)

Microstructural parameters

The sub-structure of the wood cell, especially the secondary cell wall (S2) and its microfibril angle (MFA), influences the vibrational properties, including elastic modulus and damping, in axial and shear (Obataya et al. 2000). Secondary metabolites (extractives) and grain angle can also affect these properties (Brémaud et al. 2010; Minato et al. 2010).

Axial bending vibrational properties are primarily affected by MFA, while the shear vibrational properties are rather influenced by the cell wall matrix => measurements of both axial and shear properties on the same sample should provide insight into the structure-chemistry-properties relationships.

A compact device for the dynamic bending properties had been built in LMGC and, in the present work, a new version for dynamic torsion properties was developed and tested.

Material and Method

Material: *Acer pseudoplatanus* L. (sycamore maple, wavy maple), *Picea abies* (L.) H. Karst (resonant spruce)
4 groups of each species, 8 specimens of each group, 64 specimens in total

Nominal dimensions: 150 mm (L) × 12.5 mm (R) × 1.75 mm (T)

Environmental condition: 20±2°C and 65±5%RH, stabilized for more than 3 weeks (Brémaud and Gril 2020)

Length of span: 80 mm

The mass moment of inertia (I_m) of the downer clamp set was experimentally calculated with a plastic specimen: 2.6 ×10^{-6} kg·m^2

$$I_m = \frac{ab}{12}\left[\frac{G_p C b^2}{S\pi^2 {f_t}^2} - \rho_p(a^2+b^2)\left(h+\frac{S}{3}\right)\right]$$

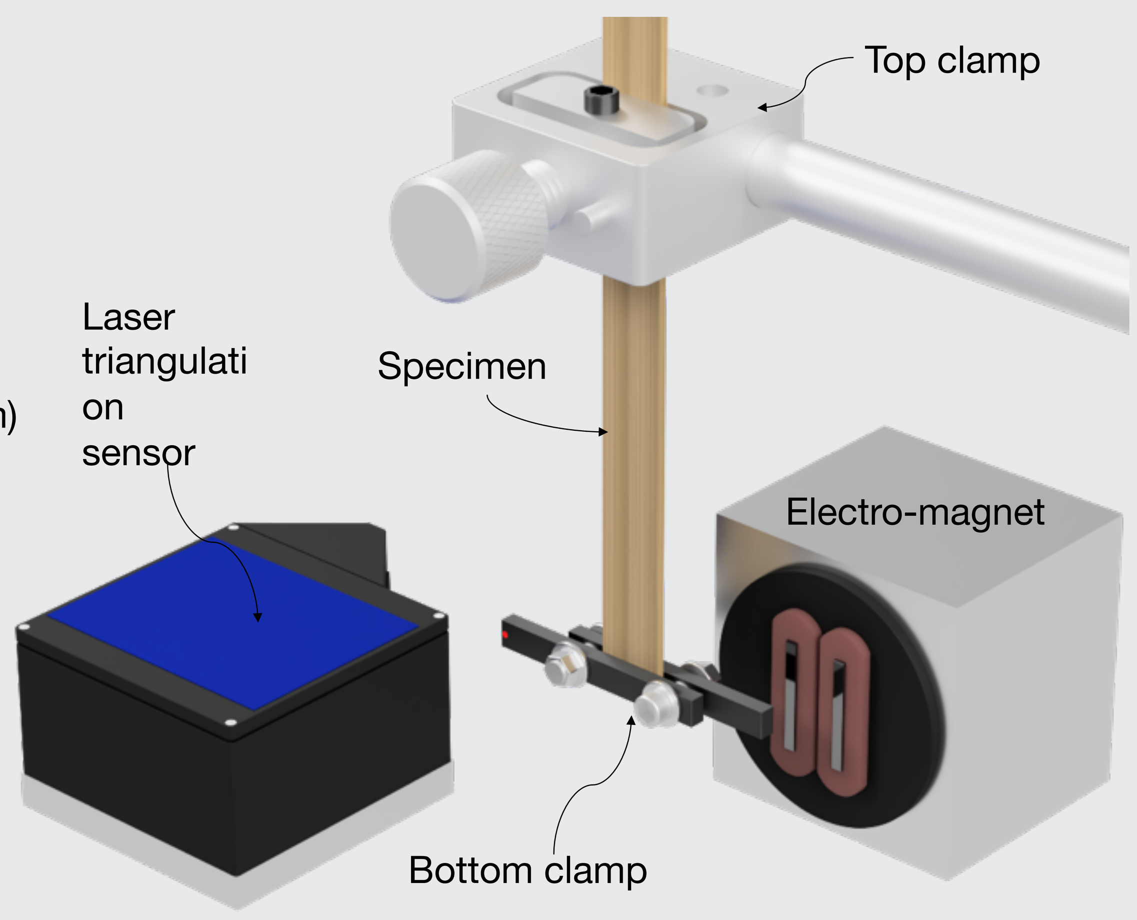
The elastic modulus of shear is then calculated with the following equation:

$$G = \frac{12\pi^2 f_t^2 S}{Cab^3}\left[I_m + \frac{\rho ab(a^2+b^2)}{36}(3h+S)\right]$$

Cross-section of the specimens (a, b)

a: width of the specimen (m) b: thickness of the specimen (m)
S: span between clamps (m) f_t: resonant frequency (Hz)
h: length of the small section clamped in the bottom clamp (m)
ρ: density of specimens (kg/m³)
ρ_p: density of the plastic specimens (kg/m³)
G_p: Shear modulus of plastic specimens (Pa)
C: $1 - 0.6302/(\frac{a}{b})$ (Ono 1980)

Vybris-Torsion device set-up



Results & Discussion

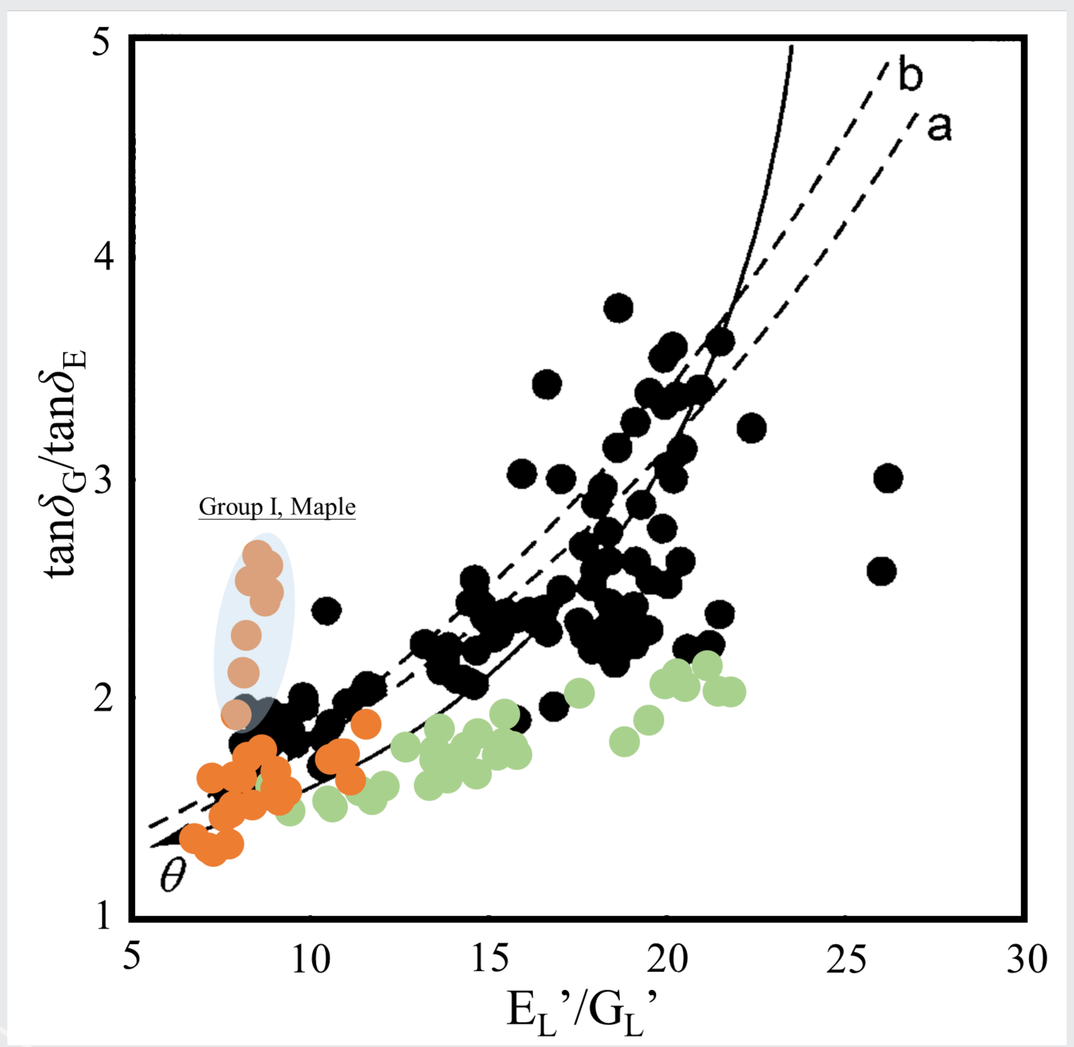
The longitudinal dynamic elastic modulus (E_L') and damping (tan δ_L) were measured by the "classical" Vybris device (Brémaud 2006) in bending

The shear modulus (G_{LR}'), its damping and the natural torsion frequency (f^G) of each specimen were also acquired

Our correlation data of tanδ_G/tanδ_L with *E'/G'* have trends similar to those in the literature (Obataya et al. 2000) with low *E'/G'* ratio for wavy maple (6.7 ~ 11.5) and a high ratio for spruce (8.9~21.8). This is in agreement with data from Nozaki et al. (1988), with 8.6 values for maple and 17.8 for spruce, and with the possible range of *E'/G'* ratio obtained by Carlier et al. (2018) of 5.2 ~ 24.3 for resonant spruce and 4.2 ~ 11.5 for wavy maple.

The axial-to-shear ratios in damping (tan δ_G/tan δ_L), compared to the possible range from Carlier et al. (2018), is 1.6 ~ 3.3 for resonant spruce, and 1.7 ~2.8 for wavy maple. Our data for the groups of resonant spruce are relatively low, while those from group I of maple fits with this possible range.

However group I of wavy maple is out of the general trend for *E'/G'*. Their density are the highest (0.72 g/cm³) among the wavy maple groups (0.53 ~ 0.69 g/cm³) but this could not explain the unusual trend, so the examination on the other aspects should be conducted and more experiments should be done to verify the representative of the current data for this group.



Comparison of the present data with literature (Obataya et al. 2000, the figure has been revised). Black dots are the experimental values for spruce in the literature data: (a) is the regression line for spruce, (b) is the regression line from 101 species and θ is the cell wall model developed in the literature. Color (present data): orange dots correspond to wavy maple; green dots to resonant spruce.

Perspectives

The preliminary results suggest that the range of values of measured properties are realistic when compared with literature values
Yet, some non-fitted data worth a further examination for their singularities, supported from the other aspects
Also, trends in the data still need to be examined with more specimens to be clearly revealed

References

Brémaud I (2006) Diversité des bois utilisés ou utilisables en facture d'instruments de musique. (Published doctoral thesis). Université Montpellier II, France.
Brémaud I (2012) J Acoust Soc Am 131: 807–818.
Brémaud I, Cabrolier P, Gril J, Clair B, Gérard J, Minato K, Thibaut B (2010) Wood Sci Technol 44: 355–367.
Brémaud I, Gril J (2020) Holzforschung https://doi.org/10.1515/hf-2020-0028
Carlier C, Alkadri A, Gril J, Brémaud I (2018) In: Wooden Musical Instruments: Different Forms of Knowledge (Book of End of WoodMusICK COST Action FP1302), ISBN 979-10-94642-35-1. pp 119-141 / 415p.
Minato K, Konaka Y, Brémaud I, Suzuki S, Obataya E (2010) J Wood Sci 56: 41–46.
Nozaki K, Hayashida H, Yamda T (1988) Japan Soc Mech Eng 91: 653–659.
Ono T (1980) Mokuzai Gakkaishi 26: 139–145.
Obataya, E, Ono, T, Norimoto, M (2000) Journal of Materials Science. 35: 2993-3001, 6317.
Tatemiti A (1960) Oyo buturi 29: 451–457.
Viala R, Placet V, Cogan S (2018) Compos Part A Appl Sci Manuf 106: 91–103.

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