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Use of vibrational properties to categorize the different types of wood within trees - as compared to interspecific diversity

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Introduction

Different types of wood are formed during the life of trees, either systematically, or in response to environmental constraints. These different types of wood can be characterized by differences in both microstructure and chemistry (e.g. in reaction Vs. normal wood) or mostly in chemistry (e.g. in heartwood vs. sapwood). Viscoelastic vibrational properties (specific dynamic modulus of elasticity E'/ρ and damping coefficient $\tan\delta$) can constitute interesting markers of such differences, as E'/ρ is primarily affected by orientation of wood elements (microfibril angle or sometimes grain angle), while $\tan\delta$ is strongly dependent on the chemical composition of the cell wall matrix substance (amorphous polymers and extractives). Secondary metabolites (extractives), in particular, can modify damping to a great extent, and are strongly connected to botanical classification. In our previous contribution to the International Plant Biomechanics Conference, we presented how vibrational properties, and especially damping coefficient, could be considered as a marker of taxonomical classification (Brémaud et al. 2009). The present paper aims at observing the way in which such diversity in vibrational properties is built, through the different (micro-) structural and chemical features associated to the different types of wood formed during the life of trees, either systematically or in response to occasional stresses. Experimental results on heartwood Vs. sapwood and on compression Vs. normal wood are presented for contrasted species. These results will be compared to other information from the literature in order to build a typology of wood types within trees on the basis of vibrational properties.

Materials and methods

Samples of heartwood and sapwood from the same tree were collected from 16 species (4 softwoods, 2 temperate hardwoods and 10 tropical hardwoods). Total number of tested specimens amounted to circa 250 for heartwood and circa 130 for sapwood. Samples of compression wood and of normal or opposite wood were collected from 3 softwood species (Brémaud et al. 2013) and from 1 atypical hardwood (Cabrolier and Brémaud 2015, presented to PBM8). For a sub-set of studied species, the sampling covered full radial variations from pith to bark.

Experiments were conducted on small specimens in longitudinal direction ($150 \times 12 \times 2 \text{ mm}^3$, $L \times R \times T$ or $L \times T \times R$). Vibrational properties were measured using non-contact forced bending vibrations (Brémaud et al. 2012). Systematic tests were done on "air-dry" wood conditioned at 20°C and 65% RH. For a sub-set of specimens, vibrational measurements were also conducted at different relative humidities and on water-saturated wood. FTIR-ATR spectra were obtained in order to get some comparative information on chemical composition.

Results and discussion

The analysis of the relation between damping coefficient ($\tan\delta$) and specific modulus of elasticity (E'/ρ) provides a way to separate effects of orientation (microfibril angle or grain angle) from those of changes in chemistry. When orientation effects only are involved, a general

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and “standard” trend curve between $\tan\delta$ and E'/ρ is observed (Brémaud et al. 2012). When chemical composition is changed, $\tan\delta$ is increased or decreased at a given value of E'/ρ . When observing compression Vs. normal wood of softwoods, E'/ρ was decreased by high microfibril angle (as is well known), however damping was lower than expected, due to more condensed type of lignins in compression wood (Brémaud et al. 2013). However this figure was less clear in the case of compression wood formed in an atypical hardwood (Cabrolier and Brémaud 2015). This raises the question of a potential of the type of lignins to discriminate vibrational properties between softwoods and hardwoods. This might be explored by comparing sapwoods of different species (that are supposedly not yet impregnated by extractives). However, if sapwoods do exhibit, in average, a “standard” damping, this is less true when observing different species separately: in some species sapwood has “atypical” damping also. In some case this was found to be due to precursors compounds present in sapwood, having an opposite effect to the final extractives in the heartwood (Yano, 1994). When comparing wood types formed in a same tree, the heartwoods had a much higher inter-specific diversity than the sapwoods did. The heartwood formation resulted in differences in damping between sapwood and heartwood from 0% to -50%. When observing the moisture-dependence of vibrational properties, different trends were observed depending on wood type, and also on species. The observation at higher moisture content can be better related to the situation in the living tree, on one hand. But mostly, analysis of these trends in moisture-dependence of damping can help to study some hypothesis about the link between chemical nature of extractive, and their “mechanical activity” (Minato et al. 1997, 2010).

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