Potential for estimating the age of instruments by characterisation of wood properties via acoustics

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Introduction

The performance of musical instruments is sensitive to several wood properties that are affected by aging. These wood properties also change with temperature and humidity in ways that interact with (and change as a result of) aging processes. This offers possibilities for estimating the age of instruments by the characterisation of wood properties through acoustic assessment.

Aging processes – effect strength and hygroscopicity

Most significant is degradation of the hemicellulose and amorphous cellulose, which acts to slowly change the microstructure, weakening the connection between the molecular components of the wood cell wall (notably the strength giving crystalline cellulose and the lignin matrix). Effects of this include a loss in mechanical stiffness, although this loss may be masked by the same chemical processes reducing the degree of hygroscopicity and, therefore, reducing the equilibrium moisture content, and so increasing the stiffness for a given external environment.

Moisture content – the all-important consideration

Even very small changes in moisture content can result in perceptible differences in instrument sound. This is caused by the interaction of dimensional changes, stiffness changes and mass changes.

Wood stiffness increases with decreasing moisture content (below fibre saturation) due to the increase in the number of hydrogen bonds between the molecular components of the cell wall. Aging causes a reduction in equilibrium moisture content (due to reduced hygroscopicity) and, if taken into consideration, the consequences of this could be used to infer age. This requires quantifying both the equilibrium moisture content and the relationship between the properties and moisture content. This is necessary for understanding how the properties influence instrument performance so that acoustic measurements made over a range of moisture contents (within a safe range) could be used to estimate wood properties and, from their moisture relations, estimate age.

Illustration using low temperature thermal treatment as an analogue for aging

Low temperature thermal treatment is an imperfect analogue for aging of wood, but does allow the exploration of degradation mechanisms via an accelerated artificial process. Results of a study of properties of Scots pine wood assessed by acoustic non-destructive testing and NIR spectroscopy are reported by Ridley-Ellis et al. [2014] in which the effect of changing equilibrium moisture content is removed by measuring the wood in the oven-dry condition. Figure 1 shows the second derivative of NIR spectra for samples treated at 110 ºC over a period of 24 weeks and the inferred chemical changes (particularly in the amorphous carbohydrates) that accompanied a steady dry mass loss of 0.022%/day and a stiffness loss of 0.04%/day (Figure 2) (assessed by impact excitation acoustic resonance).

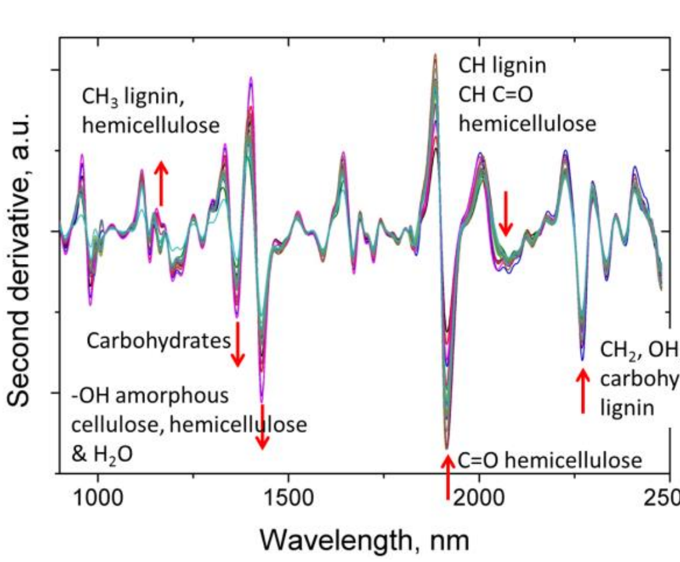

Figure 1: The second derivative of NIR spectra for Scots pine artificially aged at 110 ºC over a period of 24 weeks

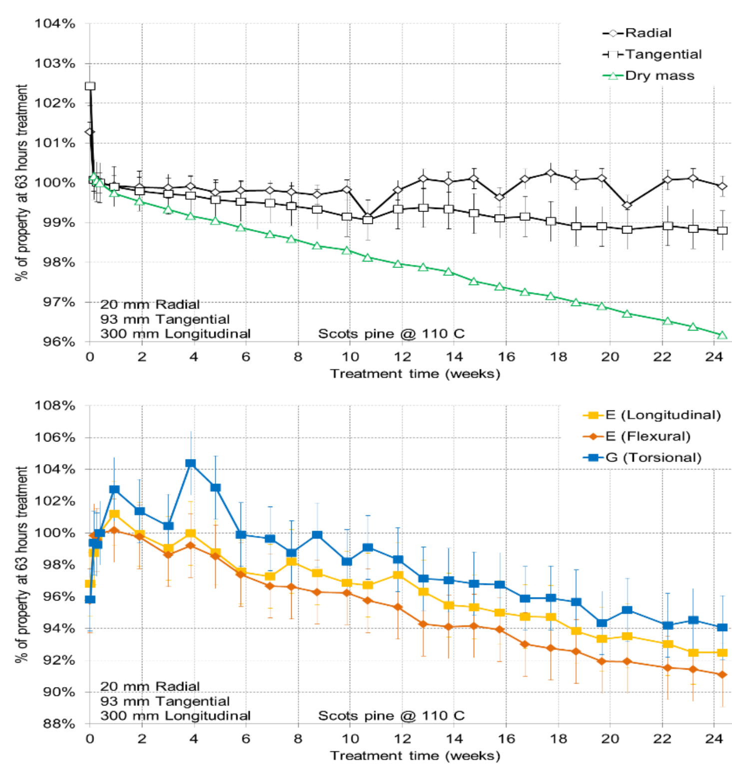

Figure 2: Dimensional changes, mass loss and stiffness loss for Scots pine artificially aged at 110 ºC over a period of 24 weeks

Consequences for musical quality

The degradation of hemicellulose and amorphous cellulose results in a loss of wood density. Density also reduces due to the loss of volatile extractives and, for a given external environment, moisture content (due to reduced hygroscopicity). The loss in density has an effect on the acoustic properties of the wood that acts in the opposite direction to the loss in stiffness. For a constant stiffness, loss in density raises natural frequencies while, for a constant density, loss of stiffness lowers natural frequencies.

Dimensions also change as a result of aging as the loss of amorphous components causes the wood to shrink and the lower equilibrium moisture content means less swelling (relative to oven-dry dimension) for the same air temperature and humidity. This will have the most profound effect on thin components such as tops and backs of string instruments resulting in a drop in resonant frequency and increased amplitude of vibration (for constant stiffness and density).

Summary

Dimensions, stiffness and mass are the very properties that instrument makers manipulate in order to improve the sound quality of instruments and all three are affected by aging processes of wood. Moisture content is a vitally important factor that absolutely must be considered in research into the effects of aging on instrument performance and inferring age from acoustic measurements. Specifically, changes in equilibrium moisture content, and variation of properties with moisture content should be quantified lest the changes that are due to moisture are confused with the changes due to aging. This does, however, open up opportunities for inferring the age of instruments through characterisation of stiffness, internal damping, equilibrium moisture content, mass and shrinkage by measuring acoustic properties across a range of temperature and humidity that is no greater than typical daily and seasonal variation.

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References

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