A NEW APPROACH FOR THE CHARACTERIZATION OF THE RESONANCE WOOD

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M. Caniato1, S. Favretto1, E. Lucchini1

1Dipartimento dei Materiali e delle Risorse Naturali, University of Trieste, Via Valerio 2, 34127 Trieste, Italy; mcaniato@units.it; sfavretto@units.it; lucchini@units.it

ABSTRACT
In this paper a new approach for the characterization of the resonance wood is described. In order to investigate the wood microstructure an intensive imaging work has been done using innovative methods, i.e. X-ray synchrotron light micro-tomography coupled with the scanning electron microscopy. Several samples of Abies Picea were examined coming from the Val di Fiemme (Italy). The geometrical and morphological information obtained by robust image processing analysis was used to feed a Finite Element Method model for further acoustic simulations. The method helped us to show how the microstructure of this material determines its acoustical macro-behavior, allowing an objective sort between the high quality resonance wood and the worse one.

INTRODUCTION
In the last years several musicians, scientists and musical instruments makers deal with the understanding of microscopic properties of different woods in order to realize, for example, piano soundboards.

The knowledge in this field is both from scientific approaches and from empirical methods. Many studies were carried out to determine the mechanical and micro-structural wood properties in order to link them to the resonance macro-behaviour and therefore to obtain measurable quantities [1,2,3]. Nowadays, for example, it is well known that spruce Young modulus for the violin upper plate and that one of the maple lower plate must be of a precise value [4]. There are nevertheless other parameters and variables which characterize and influence the resonance wood quality, such as the climatic stands, the humidity content [5], the temperature fluctuations and the type of seasoning.

The aim of this paper is to evidence the importance of resonance wood microstructure as acoustic agent for the macro-behaviour of this material. A scientific method is then possible in order to sort out different resonance wood found in wood trade. This approach supplies a solid, objective and repeatable method to discriminate the various kind of wood in nature.

Non-invasive X-ray computed microtomography (µ-CT) was used combined with scanning electron microscopy (SEM) to image the inner wood structure. The revealed micro-geometry was quantitatively investigated and further modelled in a finite element method (FEM) modal simulation for comparison between the different microstructures.

MATERIALS AND METHODS

Investigation with X-ray µ-CT

X-ray high resolution tomography (µ-CT) was performed by synchrotron light at SYRMEP beamline of the ELETTRA synchrotron lab in Basovizza (Trieste).

Micro computed tomography is one of the most advanced techniques in the field of non-destructive evaluation test. It allows imaging of the internal microstructure of different objects and materials, measuring the three-dimensional X-ray attenuation coefficient map of the
investigated sample. X-rays pass through the object, and the transmitted intensity is recorded as a two-dimensional image[6,7]. The acquired data are elaborated to create the final result which consists of a sequence of bi-dimensional grayscale images, each one representing a horizontal slice of the original object. In other words this means that tomography enables us to look at slices of the investigated object without physically cutting it. When X-rays are produced by synchrotron light sources we usually handle a monochromatic parallel beam, with a high brilliance and high spatial coherence, thus allowing both the traditional absorption scanning mode and the so called phase contrast tomography. The nominal resolution of a µ-CT dataset is usually given in terms of pixel size (or voxel size in 3D). In our datasets it is of 4.5 micrometers.

![Image of X-ray slices](image)

Fig. 1 - Once the slices are available the 3D volume can be created just stacking the slices. The internal structure can be rendered as well as explored along different orthogonal planes.

Different cubic samples were cut out from the central part of three Abies Picea boards provided by Fazioli S.r.l. (Sacile, Italy). Samples with a horizontal section size of around 5x5 mm were extracted. No further sample preparation is necessary for tomography. A vertical thickness of around one centimetre was reconstructed slice by slice with a spatial resolution of 4.5 micrometers. Samples were arranged according their quality, from the best to the best worst. We will refer to them in the next as to A, B and C.

To evaluate the porosity, as well as many other geometrical and morphological parameters, it is necessary to operate on a binary image, i.e. an image containing only zeros to represent the void phase and ones to represent the solid phase. Once the threshold is identified, any voxel is assigned to one of the two classes, according its value, if lower or higher than the threshold itself.
Quantitative analysis on reconstructed volumes and precise recognition of geometrical elements were achieved by mean of standard and custom developed software based on Matlab Imaging Toolbox 6.5.1 [8]. Not only then material density can be evaluated quantitatively, but also several purely geometrical or morphological parameters related to the cell size distribution were measured on the basis of statistical analysis. Hereafter an idea of the processing method is given (see Figure 3) and numerical results are presented for porosity $\phi$, cell diameter $D$ and cell walls thickness $w$ (see Table 1).

Fig. 3.- Quantitative measurements obtained from $\mu$-CT images.
Table 1.- Summary of numerical results calculated from μ-CT images.

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Scanning microscopy investigation
The second step of the imaging work involved scanning electron microscopy (SEM). The analysis was carried on at the laboratories of the University of Trieste.
The investigation by SEM allowed us to have a clear and bright understanding of the inner cells microstructure (basically, an insight look with a deeper spatial resolution, even if the 3D information is missed). Working at the higher resolution (i.e., enlargement of 1’000’000 x) we reach one nanometre of spatial resolution, while traditional optical microscopy supplies only 1’000 x.
The equipment used was a Leica scanning electron microscopy Stereoscan 430i with Oxford Link X-rays microanalysis. All the specimens, as they are organic and therefore non conductive, were previously metallized. Different microgeometries and hand-made porosity of analyzed wood were already described and they were also discussed in our previous works [9].

Fig. 4.– The microstructure of low quality spruce imaged by SEM (100 x).

Fig. 5.- Particular of a cell in spruce (low quality sample). Part of the structure was a bit altered during sample preparation.
**Finite element analysis**

The microstructure of the resonance wood influences the macro-behaviour of this material: the irregular geometry determines its peculiar acoustic properties. A finite element simulation is here used to show how the quality of this visco-elastic material can be investigated. The 2D wood microstructures obtained from the SEM analysis were simulated in order to obtain the modal behaviour versus frequency (see Figure 6).

![High quality sample](image1.png)

![Low quality sample](image2.png)

Fig. 6.— Micro-geometries used in finite element model.

![Comparison between high and low quality](image3.png)

Fig. 7.— The obtained modal trend versus frequency.

The trend of the modes of the low quality spruce shows clearly that this microstructure is not indicated for soundboard because it vibrates more easily than the high quality. This is due to the late wood in high quality sample that acts as a reinforcing structure for the material [9].
CONCLUSIONS

In this paper a scientific method based on innovative techniques was described and used in order to sort out different quality of resonance wood. Two different microstructures were tested and compared with X-ray microtomography and scanning electron microscopy coupled with finite element method. The results show different trend of the two analyzed geometry that of course motivates the choice of the best wood quality to make musical instruments. The presented work represents the prosecution of our previous research activities on wood that aimed to demonstrate the clear dependence of the macro-acoustical characteristics on the microstructure of the resonance woods.

References