ICA 2013 Montreal
Montreal, Canada
2 - 7 June 2013

Noise
Session 3pNSc: Joint Poster Session on Noise and Architectural Acoustics (Poster Session)

3pNSc13. Green cork-based innovative resilient and insulating materials: Acoustic, thermal and mechanical characterization
Roberta Di Monte, Marco Caniato*, Ilan Boscarato, Jan Kaspar and Orfeo Sbaizero

*Corresponding author’s address: Department of Engineering and Architecture, University of Trieste, Trieste, 34100, Trieste, Italy, mcaniato@units.it

Nowadays, efficient thermal insulation is a principal requirement for buildings and, accordingly, huge amounts of insulators are applied in the constructions, particularly for external walls, radiant floor, etc. Acoustic insulation is another of the most stringent parameters to be taken into account both in the construction of new buildings or their rejuvenation in order to obtain good internal comfort. On the other hand, the use of bio-derived construction materials is gaining stronger and stronger interest. Cork has a low density (120-240 kg m⁻³) and can be regarded as a hydrophobic and viscoelastic material, with good thermal and acoustic insulation properties. With respect to wood, it presents good resistance to microbial activity and water. Last but not least is the negative carbon fingerprint of cork-based materials. Recently a new class of polymer - inorganic oxides - cork composites has been reported, which features enhanced thermal and acoustic properties with respect to traditional commercial composites and that maintains, at the same time, all the favorable properties of conventional cork-base composites.

Published by the Acoustical Society of America through the American Institute of Physics
Introduction

Nowadays, efficient thermal insulation is a principal requirement for buildings and, accordingly, huge amounts of insulators are applied in the constructions, particularly for external walls, radiant floor, etc. Acoustic insulation is another of the most stringent parameters to be taken into account both in the construction of new buildings or their rejuvenation in order to obtain good internal comfort.

On the other hand, the use of bio-derived construction materials is gaining stronger and stronger interest. Cork has a low density (120–240 kg m⁻³) and can be regarded as a hydrophobic and viscoelastic material, with good thermal and acoustic insulation properties [1]. With respect to wood, it presents good resistance to microbial activity and water. Last but not least is the negative carbon fingerprint of cork-based materials [2]. Recently a new class of polymer – inorganic oxides – cork composites has been reported [3], which features enhanced thermal and acoustic properties with respect to traditional commercial composites and that maintains, at the same time, all the favorable properties of conventional cork-base composites.

EXPERIMENTAL SECTION

Materials

Sample materials were prepared as described in [3] using aliquots of cork, nanostructured oxides [4] and an appropriate binder, using different mixing/milling procedures followed by a low temperature ageing to ensure proper binding and particles adhesion. Typical dimension of the specimens were 200 x 200 x 9-20 mm. These samples have been characterized using different techniques as described below.

Dynamic Stiffness

The dynamic stiffness for unit area of materials used under floating floors in dwellings is the principal parameter to use in order to determine the attenuation of impact sound pressure level achievable by floating floor. Standard ISO 9052-1 [5] introduces the test arrangement and the measurement method for the calculation of the following quantities: dynamic stiffness per unit area of enclosed gas, \( s'_a \); apparent dynamic stiffness per unit area of test specimen, \( s'_t \); dynamic stiffness per unit area of the installed material, \( s' \).

The apparent dynamic stiffness per unit area of test specimen \( s'_t \) is related to the extrapolated resonant frequency \( f_r \) of the fundamental vertical vibration of the resilient material under test and load plate system, as given by the equation:

\[
2 \pi f_r = \frac{4 \pi^2 m'_t (f_r)}{m} \]  
(Eq. 1)

where \( m'_t \) is the total mass per unit area used during the test.

For porous materials, if the lateral airflow resistivity, measured in accordance with ISO 9053 [6], is included in the range: 100 kPa s/m² > \( r \) ≥ 10 kPa s/m² then the dynamic stiffness per unit area of the enclosed gas has to be determined with the equation:

\[
s'_a = \frac{P_0}{d \epsilon} \]  
(Eq. 2)

where \( P_0 \) is the atmospheric pressure, \( d \) is the thickness of the test specimen under the applied static load and \( \epsilon \) is the porosity of the test specimen.

In this case, the enclosed gas could be considered as a further spring, connected in parallel with the spring due to the material itself and the dynamic stiffness per unit area of the resilient material can be determined with the equation:

\[
s' = s'_t + s'_a \]  
(Eq. 3)

In case of high airflow resistivity the \( s'_a \) contribution could be considered not influential.

The results shall be the mean value of the respective measurements made on minimum three test specimens, rounded to 1 MN/m³.

For the determination of resonance frequency the acoustic laboratory tests of the Department of materials and natural resources at University of Trieste uses pulse signal technique, as described in ISO 7626-5 standard [2]. The measurement set-up is composed of: impact hammer PCB Piezoeletronics® Mod. 086C03, N. 26753; accelerometer Dy-tran® Mod. 3023M2 Triaxial (Figure 1); hardware National Instruments® mod. NI 9234; software LabVIEW® Sound and Vibration Toolkit for signal acquisition.
RESULTS AND DISCUSSION

Thermal and Mechanical Properties

Insulating and resilient materials based on agglomerated cork are widely employed in the construction of the buildings due to their visually attractive appearance, their good thermal insulation properties, and the natural origin of cork. Already in the 90’s, some 3–4 million square meters of cork parquet were laid each year in Germany [7]. Generally speaking, two types of cork based insulating panels are present on the market: the so-called natural and black cork. The former is normally prepared from cork granules by low temperature routes, using different types of binders such as polyurethane to achieve adhesion of the cork particles. On the contrary, no adhesive is needed for the preparation of black cork since the adhesion is achieved by a high temperature treatment, typically above 230°C and under pressure, which favors cork expansion and adhesion of the particles favored by the suberin, naturally present in the cork [8]. Thus no synthetic adhesive is needed to prepare these materials leading to commercially attractive “green” materials. In addition, thermal conductivity of black cork is significantly lower – $\lambda = 0.036 \text{ W/mK}$ – as compared to natural cork that typically features values of $\lambda$ of 0.042-0.044 W/mK. On the other hand, the applied thermal treatment significantly degrades and modifies the nature of the cork, leading to appreciable VOC (volatile organic compounds) emissions and even smelling materials, whereas negligible VOC emissions were observed for natural cork [7].

Accordingly, there is strong interest in developing novel materials, based on natural cork which, however, show improved thermal and acoustic properties. We have therefore used nanostructured porous materials that are known to improve thermal insulation properties [9] to prepare a series of nanostructured oxide-cork composites. The relevant mechanical and thermal properties of the novel materials are reported in Table 1. A perusal of the reported data shows that we obtained mechanical properties equivalent to those of commercial cork-based panels. Noticeably, consistent with the premises [8], excellent thermal insulation properties were achieved that are comparable to those of black-cork, even though natural cork was employed in our work.
**TABLE 1.** Properties of the cork based materials used in the present work. All the values were measured using at least 6 specimens.

<table>
<thead>
<tr>
<th>Property</th>
<th>Measured Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity $\lambda$ (W/mK a 10°C)</td>
<td>0.036</td>
<td>UNI EN 12667, ISO 8301 e ASTM C518</td>
</tr>
<tr>
<td>Specific heat (KJ/KgK)</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Capillary diffusion (Kg/m²h¹/²)</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td>Moisture content</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Time humidity resistance</td>
<td>excellent</td>
<td>no de-aggregation</td>
</tr>
<tr>
<td>Boiling water resistance 1 h</td>
<td>excellent</td>
<td>no de-aggregation</td>
</tr>
<tr>
<td>Vapor permeability (Kg/smPa)</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Load and module of rupture by flection Kg/cm²</td>
<td>0.08</td>
<td>155 x 33.6 x 9 mm, ASTM 203</td>
</tr>
<tr>
<td>MPa</td>
<td>0.178</td>
<td></td>
</tr>
<tr>
<td>Compression resistance (Kg/cm³)</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Linear dimensional variation from wet to dry (%)</td>
<td>&lt;0.5</td>
<td></td>
</tr>
</tbody>
</table>

**Acoustic properties**

Dynamic stiffness test were carried out on the prepared layers to determine the frequency resonance supplied by the material. Examples of the observed FFT patterns (x axis: Frequency domain; y axis: excitation amplitude) are reported for different specimens in Figure 2a (bad behaviour) and Figure 2b (good behaviour).

![FFT analysis](image_url)

**FIGURE 2a.** Examples of the observed FFT analysis bad pattern.

Specimen 229 showed a 4 peaks frequency pattern; the other ones showed a 2 peaks pattern pointing out a bad phase mixing.

This fact cannot supply reliable values for impact sound pressure level index for all kind of floor structures[10].

Last specimens show very good agreements in term of dynamic stiffness values compared with traditional cork based resilient layers and especially compared with traditional TNT based or rubber based resilient layers.
Clearly, quite different acoustic behavior was detected according to the specimens considered, even though apparently identical experimental procedures were employed in the preparation of the samples. The observation of the double peak pattern in the FFT analysis response implies the presence of two (or more) different and separate phases inside the specimen. Consistently, a careful re-examination of the samples and the preparation route revealed the presence of inhomogeneous regions in the samples, as detected by their sectioning (Figure 3), which was attributed to the difficulty of achieving a proper mixing and compatibility of the different components of the layer. Importantly, such non-homogeneity, which result in degradation of the sample properties, can be detected with difficulty using conventional techniques and often destructive analyses are needed. Thus the present results show that the acoustic measurement can act as a very efficient tool to assess quality and homogeneity of composite materials.

![FIGURE 3](image)

**FIGURE 3.** Section of the cork panel showing evidence for non-homogeneous distribution of the binding and oxide components (indicated by the arrows).
FINAL REMARKS

Preliminary investigation was carried out on a nano-structured oxide-cork based composites. The layers are characterized by highly efficient thermal insulation property compared to conventional natural cork based materials. The acoustic laboratory tests have demonstrated that the behavior of the layers shows good dynamic stiffness property, comparable with commercial cork panels. Worth of noting is that extremely simple acoustic measurements provide an efficient and rapid route for detecting process quality, since even fine dis-homogeneities in the prepared specimens could be easily discriminated.

ACKNOWLEDGMENTS

Regione Friuli Venezia Giulia, POR-FESR 2007-2013, Asse 1, Attività 1.1b “Green Boat Design” project is gratefully acknowledged for financial support.

REFERENCES

6. ISO 7626-5:1994 Vibration and shock - Experimental determination of mechanical mobility - Part 5: Measurements using impact excitation with an exciter which is not attached to the structure