

**DETERMINATION OF ACOUSTIC PARAMETERS OF
BIO-BASED MATERIALS DISTENDED FOR BUILDING:
APPLICATION CASE TO ALEPPO PINE WOOD CORK AND
THEIR COMPOSITES**

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ABSTRACT

In this work, we are interested to incorporating acoustic comfort in buildings by using bio-based materials. More specifically, this work aims to determinate experimentally the sound absorption coefficient (α) and the sound reduction index (R) in three different samples. The first sample consists of Aleppo pine wood (*Pinus halepensis*) with two different configurations (solid wood and laminated timber wood). The second sample consists of a black agglomerated cork (*suber*) with two different thicknesses. The third sample consists of sandwich assemblies obtained by superimposing two wooden layers (solid or laminated timber wood) bonded with an inter layer cork. In this experimentation, we have used Kundt tube to determine sound absorption coefficient and AcouSYS V2.0 software to predict the sound reduction index. The obtained results showed that the first parameter (α) is influenced by the thickness of material. The second parameter (R) of symmetrical and asymmetrical sandwich assemblies of solid laminated timber wood with an interlayer of black agglomerated cork even shows good performances.

KEYWORDS: Sound absorption coefficient; sound reduction index; Aleppo pine wood; black agglomerated cork; Kundt's tube, AcouSYS V2.0 software.

INTRODUCTION

As in many industries, the building trade has recently begun to realize the wonderful potential of bio-based materials and responses they are able to bring to environmental issues. This fact brings the builders to place sustainable building and bio-based materials among the future markets.

In fact, efforts against the discomfort and health problems caused by noise and vibration in buildings are highly requested from both builders and scientists (Cerezo 2005). The passive acoustic treatment, mainly involving porous materials (wool, moss), is one of the most common ways to reduce noise (Dupont 2002). However, among the bio-based materials that gave satisfactory results in sound insulation we can find Aleppo pine wood and black agglomerated cork with composite panels. Two resources which are abundantly available in Algeria, namely, in the forests of Bejaia and Boumerdes. In this work, we have conducted two experiments. Firstly, we have measured the acoustic absorption coefficient of samples of black agglomerated cork, Aleppo pine wood and their assemblies using Kundt tube (for a frequency of excitation varied between 100 and 1600 Hz).

Secondly, we have calculated the sound reduction index using AcouSYS V2.0 software of symmetric and asymmetric composites of wood and cork with two different thicknesses. The asymmetric assemblies having 80 mm of interlayer thickness are of particular interest for use in a building. Asymmetric configuration (solid wood/black agglomerated cork (thickness = 80 mm)/ laminated timber wood) for a total thickness of 120 mm, has the best results for the sound reduction index ($R_w + C = 27$ dB). This result is comparable to the performance of some commonly insulating honeycomb.

MATERIAL AND METHODS

Material

- **Black agglomerated cork (BAC):** Three tested cork specimens have a circular section with 100 mm of diameter and 40, 80 mm thickness (Fig. 1a), the agglomerated cork is a material derived from the bark cork (*Suber*) oak tree (Djema 2009). It is obtained from cork granules after grinding tablets in an autoclave at 350°C. The resin contained in the bark plays the role of a natural bind to agglomerate the granules. When the panels come out of the autoclave, they will be traversed by a flow of water for cooling.
- **Aleppo pine wood (APW) :** Six tested specimens have a circular section with 100 mm of diameter and 20 mm of thickness, two different configurations has been tested, three samples for solid wood and three other samples laminated timber (Fig. 1b, c). Aleppo pine (*Pinus halepensis*) is a conifer that belongs to the *Pinacea* family. It is a rustic species, which characterizes the semi-arid Mediterranean bioclimatic zone (Saad et al. 2014). The wood of Aleppo pine is a species of lightings, its low water requirements (300 mm or even less) and the abundance of grains allow it to rapidly colonize the most varied stations. In Algeria, the forest area contains an average of eight hundred thousand hectares of Aleppo pine of (Daoui et al. 2007)
- **Composites BAC / APW:** This three tested samples are obtained from superimposing two wooden layers (solid wood or laminated timber wood) bonded with an inner cork layer with thicknesses of either 40 or 80 mm (Fig. 1d). The objective is to observe the coupling effect of wood and cork on the value of sound absorption coefficient.

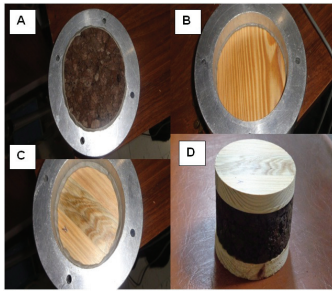


Fig. 1: Pictures representing the four tested samples: A) Black agglomerated cork (diameter = 10 mm). B) Aleppo Pine solid wood (diameter= 10 mm, thickness = 20 mm). C) Laminated timber of Aleppo pine wood (diameter= 10 mm, thickness = 20 mm). D) Composite BAC/ APW (diameter = 10 mm).

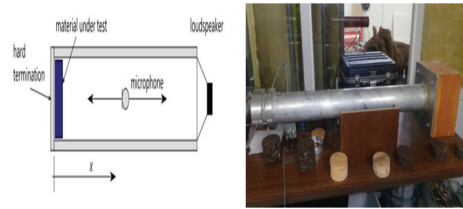


Fig. 2: Kundt tube, schematic diagram and measurement system of sound absorption.

Sound absorption coefficients (α)

The sound absorption coefficient has always been considered as one of the most important physical parameter to measure in order to characterize the acoustical efficiency. There are mainly two types of methods to determinate the absorption coefficient of acoustic materials: the reverberation room method and the impedance tube method (Cuiyun 2012). The last one is used in different thesis work, (Dupont 2002) used a Kundt tube (Fig. 2) for measuring the sound absorption coefficient of structures composed of a micro perforated plates (MPP) coupled to a rigid wall with a cavity depth d : 0.05 cm. It is also used by (Cerezo 2005) for the measurement of sound absorption coefficient at normal incidence of a hemp concrete. A report of (Atalla et al. 2004) presented the results of the measurement of the sound absorption coefficients for different panels of stone wool in different porosity percentages.

The experimental design is very often used to measure the sound absorption of a material at normal incidence. It consists of a 10 cm diameter tube, in which a loudspeaker located at one end, generates a sine wave. The waves propagate in the tube to the other end and will be reflected at the hard termination (i.e. the wood and cork samples). The sending wave frequency varies between 100 and 1600 Hz, the wood and cork samples are placed on a rigid support in the other end. Inside the tube, a stationary pressure field is established. A microphone is placed on the tube at a fixed distance from the sample, a pressure field is measured at three different places whose positions are varied manually then received by a data acquisition to be used to calculate absorption with the transfer functions of transmitted and reflected signals. The measurement is performed twice on each sample while changing the faces, each sample is placed in a circular sealed mold of 10 cm diameter, it is desirable that the sample adhered to the wall as possible which we have used a play dough. By introducing absorbing material in front of the hard termination, the reflection is reduced and as a consequence, the sound pressure maxima decrease and the minima increase. As will be shown below, the absorption coefficient can be also determined from the ratio of maximum and minimum sound pressure alone. The sound field in the tube is sensed by a microphone that can be moved along the tube axis.

Sound reduction index (R)

The measurement of the sound reduction index R is performed according to EN ISO140-3 (1995) completed by the NF EN ISO 717-1 (2013) for the expression of the unique index R_w (C; Ctr), the acoustical performance is predicted using a transfer matrix method (TMM: Transfer Matrix Method) (Foret et al. 2010) and (Munjal 1993) implemented in the AcouSYS V2.0 software. The last one is used to predict acoustic performance of multilayered structures. It is suitable for consultancy firms, industry actors, laboratories, experts or non-experts since it allows quick and complete investigations, optimizations and parametric studies. The considered systems are composites with different configurations wooden skins.

Symmetric and asymmetric assembly while playing on the cork interlayer thickness (40, 80 mm), it was assemblies of 3 layers both wood and cork as a porous interlayer with a open volume porosity (σv) of 0.8. The mechanical properties of the materials (elasticity modulus E, density ρ , Poisson coefficient ν) are obtained from various characterization measurements, the mechanical and physical parameters used for the simulation of the sound reduction index R are shown in Tab. 1.

Tab. 1: Initial parameters used for simulation the sound reduction index.

Parameters	Solid wood	Laminated timber wood	Black agglomerated cork
E (N.mm ⁻²)	14339	14700	05
ρ (kg.m ⁻³)	589	350	105
ν	0.2	0.32	0.01
σv	/	/	0.8

RESULTS AND DISCUSSION

The sound absorption property is the ability of a wall to reflect incident sound waves by attenuating its amplitude (Parviz 2006). The sound absorption coefficient α is measured according to NF EN ISO 11654. Our experiments are carried out in a Kundt's tube (in laboratory conditions of temperature and pressure), where incident sound waves are perpendicular to the specimen surface (Wang et al. 2012). The tested frequency range is 100–1600 Hz. The diameter of the specimens is 100 mm; with two thicknesses of 40 and 80 mm.

Throughout these experiments, one question is focused on that, if the nature faces influence the sound absorption coefficient. Thus, we have tested the two faces.

For the black agglomerated cork (BAC), the results obtained from the three kinds of specimens are shown. The sound absorption coefficient α varies significantly in the third octave band values, within the frequency range of 100-1600 Hz. It is noticed that the absorption curves show amplitude peaks and variable frequency position according to the considered thicknesses. Samples with 40 mm of thickness have two absorption peaks, the first is situated at the 400 Hz and reaches a value of $\alpha = 0.68$, the second is situated around 1200 Hz and reaches a value of $\alpha = 0.60$ (Fig. 3). The frequency position of the first peak tends to the low frequencies, while we notice a decrease in amplitude of the second peak, which is due to the packing effect. Samples with 80 mm of thickness have also two peaks, the first peak is observed at medium frequencies (400- 500 Hz) with $\alpha = 0.7$, the second peak at 1200 Hz with a value $\alpha = 0.55$ (Fig. 4).

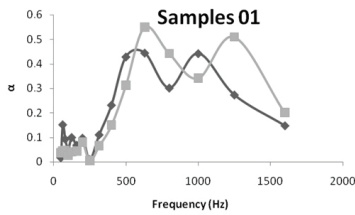


Fig. 3: Sound absorption coefficient of both sides of the samples of black agglomerated cork.

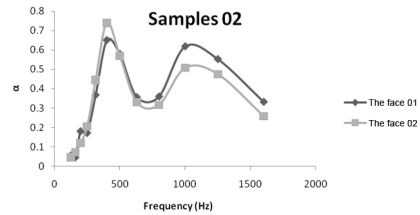


Fig. 4: Sound absorption coefficient of both sides of the samples of black agglomerated cork (thickness = 80 mm).

For the Aleppo pin wood (APW), the main results of the three specimens of each configuration (solid wood, laminated timber wood) have showed in Figs. 5, 6.

The sound absorption coefficient α varies slightly in the third octave band values, within the frequency range of 100-1600 Hz. For the whole solid wood samples and the laminated timber wood with a thickness of 20 mm. Also two peaks are observable, the first located between 150 and 250 Hz and reaches a low average value $\alpha = 0.13$ and the second about 600 Hz which reaches a value of $\alpha = 0.09$.

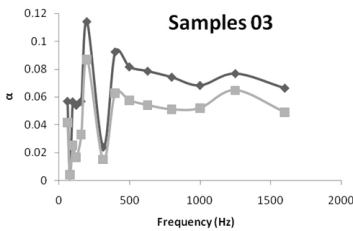


Fig. 5: Sound absorption coefficient of both sides of solid wood (thickness = 20 mm).

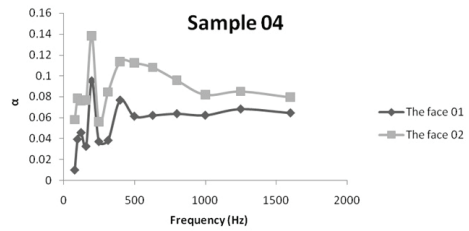


Fig. 6: Sound absorption coefficient of both sides of the laminated timber (thickness = 20 mm).

For the composites (BAC / APW), the main results of the three specimens of each composite (solid wood- black agglomerated cork- solid wood, laminated timber wood- black agglomerated cork- laminated timber wood) was showed respectively in the two Figs. 7, 8 which tell us about the influence that may have the stack of several layers of different materials on the value of sound absorption coefficient, an average values of 0.5 for the laminated timber wood and 0.45 for the solid wood.

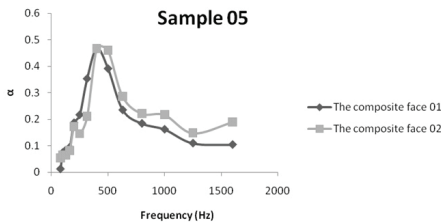


Fig. 7: Sound absorption coefficient of both sides of the composite cork/ solid wood ($e = 120$ mm).

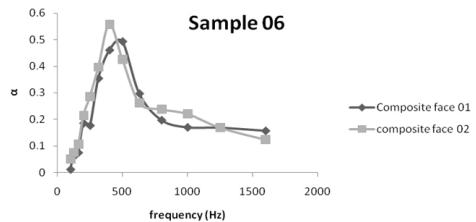


Fig. 8: Sound absorption coefficient of both sides of the composite cork/ laminated timber wood (thickness= 120 mm).

Figs. 9, 10, 11 showed respectively the variation of the sound reduction index of symmetrical assemblies (solid wood-black agglomerated cork-solid wood), (laminated timber wood, black agglomerated cork- laminated timber wood) and asymmetrical (solid wood- black agglomerated cork-laminated timber of wood).

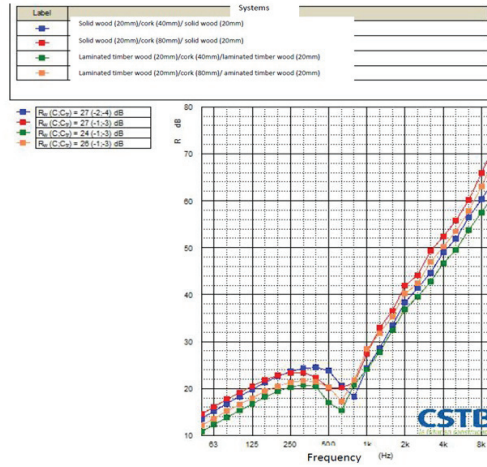


Fig. 9: Index sound reduction of symmetrical assemblies: (solid wood-black agglomerated cork-solid wood), (laminated timber wood-black agglomerated cork-laminated timber wood).

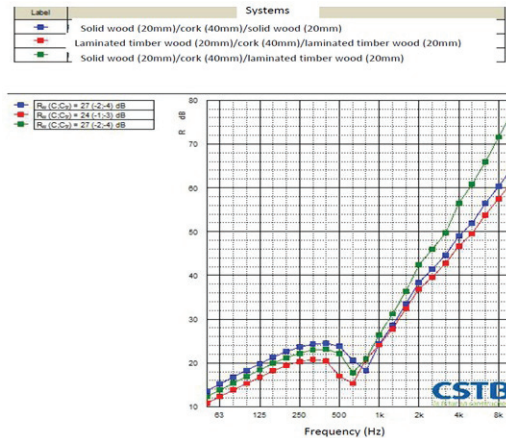


Fig. 10: Index of sound attenuation of asymmetrical assemblies cork thickness = 40 mm: (solid wood-black agglomerated of cork (thickness = 40 mm)-Laminated timber wood), (laminated timber wood-black agglomerated of cork-solid wood).

The values of the sound reduction index are influenced by the thickness of the cork interlayer. For an 80 mm of thick for the asymmetrical assemblies, values exceed to 80 dB. Also, for the thick of 40 mm, values do not exceed 75 dB. The symmetrical assemblies show a low value of about 65 dB.

For the black agglomerated cork, we notice that the peaks tend to shift to lower frequencies

when increasing the thickness of the sample. This can be explained by the difficulty of the waves to penetrate all along the thickness of the material. Hence, we note the sensitivity of the sound absorption coefficient in the state of the sample surface, it was observed that the more porous surfaces which contains more pores can show a high value of sound absorption coefficient than smooth surfaces, that one is explained by the viscous friction existing between the containing air in cork pores and it's solid skeleton (Biot 1956), then this damping exists only if the sound wave can enter the porous network and that the contact surface between the air and the cork is large. We conclude that the sound absorption capacity that has the cork varied simultaneously with the sample thickness.

For the Aleppo pin wood, curves showed the sensitivity of the sound absorption coefficient in the state of the sample surface, it is explained by the wood material inhomogeneous and the presence of the glue for the laminated timber concluded that the value of the acoustic absorption of the entire sandwich system is influenced by the first contact surface material in this case, the surface of the Aleppo pine wood. It is concluded that wood is a poor absorber.

For the composites, as might be expected, the black agglomerated of cork association with the induced wood composite weakly absorbing medium view at low frequencies (400 Hz). It is concluded that the value of the acoustic absorption of the entire sandwich system is influenced by the first contact surface material in this case, the surface of the Aleppo pine wood.

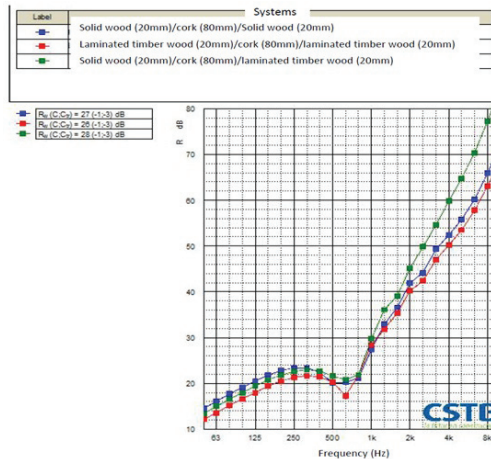


Fig. 11: Index of sound attenuation of asymmetrical assemblies cork thickness = 80 mm. (solid wood-black agglomerated of cork (thickness = 80 mm)-Laminated timber wood), (laminated timber wood-black agglomerated of cork-solid wood).

We get a good results of sound reduction index for sandwich structures in low frequencies, allows considering a use in the building for sound insulation (between two rooms of house). Indeed, the calculated specific performance is in the same order of magnitude as those of some systems used in construction as distributive partitions, example:

- **Alveolar partition of 50 mm thick:** $R_w + C = 26$ dB
- **Honeycomb partition of 72 mm thick:** $R_w + C = 29$ dB

In our case:

- **Sandwich with a total thickness of 150 mm: solid wood + black agglomerated of cork (80 mm) + laminated timber wood:** $R_w = 27$ dB + C

This informs the possibility of its use in the building sector.

CONCLUSIONS

In this work, the acoustical properties of wood Aleppo pine and black agglomerated cork and their composite structures were discussed from the experimental point of view. The goal was to determine whether these materials have an interest as insulators and sound absorbers.

The results reveal:

- The sound absorption coefficient of the materials is influenced by its thickness: more the material is thick it is more absorbing in the frequency range of (100-1600 Hz) consequently the peaks shift to lower frequencies.
- Wood Cork assemblages show no particular interest to the acoustic correction.
- The sensitivity of the absorption coefficient at the sample surface state.
- The higher values of sound reduction index (80 dB) are obtained with an "asymmetric" sandwich (solid wood / cork / laminated timber wood).
- The calculation of specific performance $R_w + C = 27$ shows the high possibility of its insertion in the field of construction.

These kind of materials add to their properties of bio-source, biodegradability, lightness, availability and low cost; a potential of sound insulation. In addition to that, they enable to be integrated into the field of construction where the builders are always looking for materials with better performance and lower cost. Mainly, in terms of energy and environmental footprint.

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