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Acoustic analysis of cement composites with lignocellulosic residues

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Abstract. The concept of environmental sustainability has been seeking a way to develop projects that reduce the impacts provided by agricultural development and the excessive consumption of natural resources. However, there is still little knowledge about the acoustic insulation/absorption behaviour of lignocellulosic materials. Hence, this study aimed to evaluate the acoustic properties of five cement panels reinforced with the following lignocellulosic materials: eucalyptus, sugarcane bagasse, coconut shell, coffee husk, and banana pseudostem, which ones have as a reference a commercial plaster used as sealing in civil constructions. The proposed panels were produced with each lignocellulosic material residue. It was produced three replicates for each type including plaster (being 18 panels in total). The sound insertion loss (SIL) measurement of the above-mentioned panels have been performed using an acoustical treated inexpensive facility developed based on the literature. The characterization of the acoustic behaviour of the studied materials were analysed according to the IEC (61260-1). The acoustic measurements have been done in the range of 20 Hz to 20 kHz and the analysis in octave bands have been performed. To make the analysis easier, the overall range of frequencies mentioned above was divided as ‘low’, ‘middle’ and ‘high’ ranges. Additionally, the measurement of thickness, density and porosity structure parameters of the lignocellulosic samples have been performed. According to the results and doing a trade-off analysis, the eucalyptus presented the overall best performance considering the overall range of analysis, being the banana pseudostem and sugarcane bagasse materials as good competitors.

Key words: alternative building material, lignocellulosic panels, sound insertion loss, residue materials.

INTRODUCTION

The concept of environmental sustainability has been seeking a way to develop projects that reduce the impacts provided by agricultural development and the excessive consumption of natural resources. All waste produced by industry and agriculture must be treated correctly, avoiding harmful consequences for the environment (Arruda Filho et al., 2012).

The use of organic waste has been developed for different applications worldwide, due to the idea of mitigating environmental pollution, as well as proposing recycling alternatives (Prusty et al., 2016). The engineering design of rural and civil buildings must take the availability of the local materials into account, encouraging wherever possible the use of natural materials that can be regenerated (Bambi et al., 2019). Natural fibers, with their porous cell structure and relatively low density, are becoming popular because they are renewable, non-abrasive, economic, available in abundance and pose lower health risks during handling and processing (Sari et al., 2016). According to César et al. (2017), most of the lignocellulosic materials can be used in panel production. Besides, these panels produced with raw materials present the following advantages: good fire resistance, good thermal and acoustic insulation, good resistance to fungus and insects attack, and they can be considered as good materials to work (Iwariki & Prata, 2008). Nevertheless, using natural fibres has some disadvantages, because they do not have uniform properties. It is because the values of their properties greatly vary as these properties are directly related to the composition of their constituents, such as cellulose, hemicellulose and lignin (Azevedo et al., 2021).

The civil construction industry is one of the biggest consumers of natural resources and energy, and this fact has encouraged researches in sustainable development area. The introduction of the concept of 'sustainability' in the building sector gradually led to the production of insulation products made of natural or recycled material; some of them are already present in the market while others are still at an early stage of production or study (Asdrubali et al., 2015).

One option to use the lignocellulosic materials in building solutions is the use of cement-bonded particle boards/panels. According to Mendes et al. (2017) these panels are products manufactured from a mixture of Portland cement, chemical additives and particles generated from lignocellulosics. Cement-bonded panels could be used in building construction improving the performance on fire resistance and thermal/acoustic insulation. However, there is still little knowledge about the acoustic insulation/absorption behaviour of lignocellulosic materials. In order to absorb sound, materials should have high porosity to allow the sound to enter in their matrix, and for dissipation (Berardi & Iannace, 2015).

According to Ghofrani et al. (2016) in general, there are two main ways to control noise: The first one is to control/reduce the sources of noises. The second one is to control/reduce the noise through the transmission path. Hence, it is important to evaluate the acoustic properties of panels produced with lignocellulosic materials. These approaches could be particularly important and useful in developing countries, which do not have well-defined recycling policies and are affected by disposal issues due to large quantities of agricultural and industrial by-products (Asdrubali et al., 2015).

Commercial plaster board is a widely used building material that can be used for indoor applications. Plaster boards are inexpensive materials and easy to use with a whole bunch of advantageous attributes. Plaster boards are considered as materials with good properties in terms of heat insulation, comply with the standards for fire safety and provide a pleasant room climate (De Korte, 2015; Butakova & Gorbunov, 2016; Schug et al., 2017).

Therefore, this paper aims to evaluate acoustically cement panels produced with lignocellulosic residues. The panels are compared with a reference commercial plaster board that is frequently most common material used as walls and roofs in civil constructions.

MATERIALS AND METHODS

The experiment was carried out at the Federal University of Lavras (UFLA), Lavras, Brazil. For the production of lignocellulosic panels, the following lignocellulosic materials were used: Eucalyptus (*Eucalyptus grandis*), sugarcane bagasse (*Saccharum officinarum*), coconut shell (*Cocos nucifera*), coffee husk (*Coffea arabica*), banana pseudostem (Musa a*cuminate*) and a commercial plaster board. Three repetitions for each kind of lignocellulosic material have been made, totalizing 15 panels (5 treatments and 3 repetitions). And, three commercial reference plasterboards were bought at specialized stores in the city.

Lignocellulosic cement composites have been developed with high initial resistance Portland cement (CPV-ARI), as mineral binder and calcium chloride ($CaCl_2$), used as an accelerator of the cement cure process. For the calculations of the components of each panel (lignocellulosic material, cement, water and $CaCl_2$), the methodology suggested by Souza (1994) was used to determine the equivalent mass of components. In the production of panels, the following parameters were applied: material and cement ratio, 1:2.75; water and cement ratio, 1:2.5; hydration water rate of 0.25; additive, 4% (based on cement mass); percentage of losses, 6%. The calculations were performed for nominal panel density of 1.2 g cm^{-3} (Souza, 1994).

In order to produce each panel, components were weighed and then mixed in a concrete mixer for eight minutes. The total mass of components for three panels equivalent to each treatment (at the same time) was mixed. After mixing, the mass of each panel was properly separated, weighed and randomly distributed in aluminium moulds of 480×480×150 mm. The moulding and stapling were carried out in a cold process for 24 hours and then panels were kept in a climatic room at a temperature of 20 ± 2 °C and 65 ± 3% relative humidity to ensure uniform drying for 28 days.

To measure the thickness (mm) of each panel, it was used as a calliper in four different points in each sample of the panels. The dimensional size and weight measured were used to calculate the thickness and density of the composites. Density (kg m^{-3}) was calculated by the relationship between the panel mass (Kg) and the panel size (m^3). All of these analyses were developed based on the ASTM standard method (ASTM D1037, 2016) and Deutsches Institut fur Normung - DIN (1982) standards.

The acoustic evaluations have been performed using insertion loss measurements of the samples. The measurements have been done using a low-cost acoustic treated facility developed based on the work of Piedrahita & Fajardo (2012). A schematic representation of the mentioned facility can be seen in Fig. 1. The chamber is divided in two identical parts. It can be observed that each chamber has 750 mm height and 480 mm side of the base. The source is placed in the first chamber and the microphone in the second chamber after the sample. The samples are placed in the intersection of the two parts and the chamber has been sealed by means of clips.

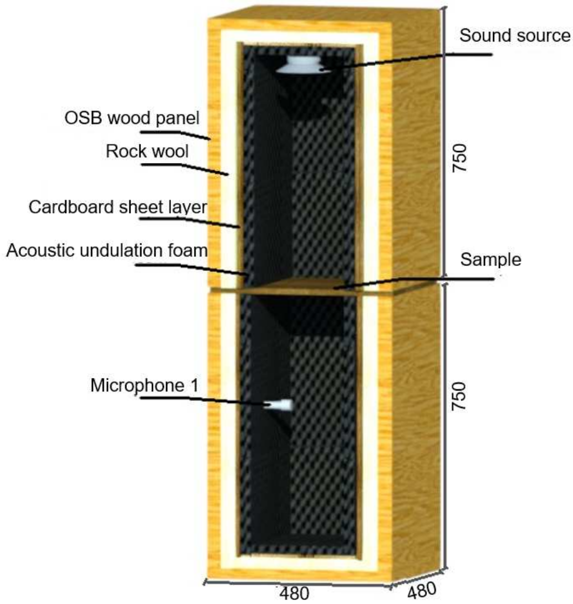

Figure 1. Facility developed for sound insertion loss measurement. Facility measurements are in mm.

The facility consists mainly of an external box made with oriented strand board (OSB wood panel) with 8 mm of thickness and internal layers of different materials. The outer box is basically used to guarantee the vibro-acoustic insulation from the external environment. The inner box was coated using three layers in the following order: rock wood, cardboard sheet and acoustic undulation. The thickness of these layers were, 50 mm for rock wool, 5 mm for cardboad sheet 25 mm for undulated foam, which ones are illustrated in Fig. 2 in order to have an ideia in terms of tickness. It is important to mention, that the acoustic foam with ondulations is to help to mitigate the sound reflecion into the chamber.

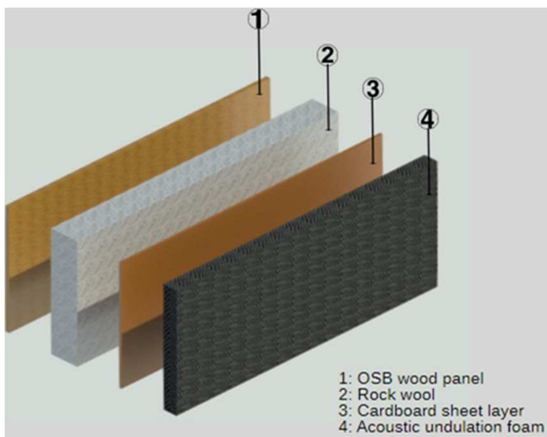

Figure 2. Internal layers of the used facility built for sound insertion loss measurement.

The sound source was located in the first chamber, and the response was measured in the second chamber through a microphone. As an excitation was used a sine-sweep signal, and through a microphone the response was measured. Through the relation output/input was obtained the frequency transfer functions, following the works of Farina (2000, 2007) and Müller & Massarani (2001). These measurements have been performed using a system composed by: a class-D amplifier, sound reproduction system, ECM-8000 and an audio interface with Phantom power using a sampling frequency of 192 kHz.

To turn possible the characterization of the acoustic behaviour of the proposed materials, the sound insertion loss of the different panels produced were analysed according to the IEC 61260-1.

During the acoustic measurements, the background noise of the room was monitored by a hot wire anemometer model HM-385®, measurement scale 0 °C to 50 °C ± 1.0 °C.

The physical structure data analysis of the cement composites (thickness in mm, density in kg m^{-3} and porosity %) were evaluated in a randomized design. The results were submitted to Analysis of variance (ANOVA) and Tukey test tools, both at a 5% significance level.

RESULTS AND DISCUSSION

The factors that determine the ability of a material to resist sound transmission include the thickness, density, and porosity of the specimen (Karlinasari et al., 2012).

In the proposed work, the thickness and porosity properties have been measured also besides the density in order to add and improve the information of the samples Fig. 3).

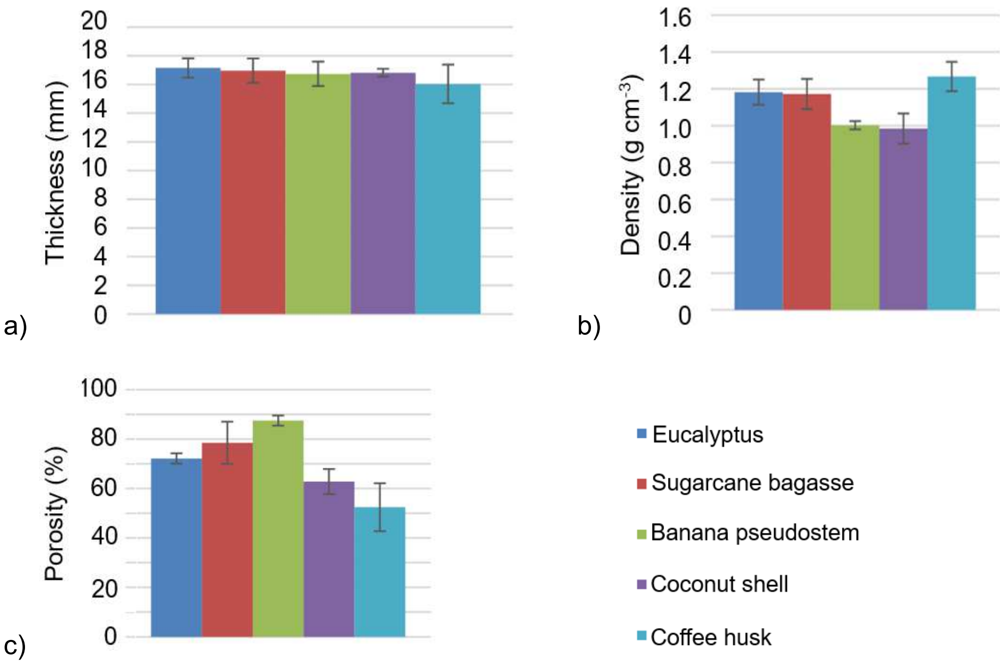

Figure 3. Physical properties of the lignocellulosic panels: a) Thickness (mm); b) Density (g cm^{-3}); c) Porosity (%) of Eucalyptus, sugarcane bagasse, banana pseudostem, coconut shell and coffee husk.

Large differences were observed in the physical properties of the lignocellulosic samples because of their different microstructures composition as a result of the chemical treatment of the raw fibres. This diversity is very interesting because it can provide considerably different porous microstructure characteristics and thus different acoustic properties.

The lignocellulosic panels thickness are similar, and all of the evaluated samples presented thickness around 17 mm. The density can be associated with the cement penetration into the permeable pores from the gaps and lumens found in the particles (Savastano et al., 2009). In our experiment, the highest density value of the composites was obtained from the panels reinforced with coffee husk followed by eucalyptus and sugar cane panels.

Pores isolated from other adjacent pores are also called 'closed' pores that allow some level of sound absorption, but only 'open' pores, which guarantee a continuous channel of communication with the external surface of the material, allow higher sound absorption characteristic (Berardi & Iannace, 2015).

For acoustic analysis through the sound insertion loss, and in order to make easier the interpretation of the data, it was proposed three groups of ranges named as 'low' (63 Hz, 125 Hz and 250 Hz), 'middle' (500 Hz, 1,000 Hz and 2,000 Hz) and 'high' (4,000 Hz, 8,000 Hz and 16,000 Hz).

The results of insertion loss analysis of the five kinds of samples and reference are shown in Fig. 4. It is important to mention, that for this metric, higher is better, and consequently the insertion loss of the reference sample is the highest one for 'low', 'middle' and 'high' frequencies. To turn possible to characterize the acoustic behaviour of the studied materials, they were analysed according to the IEC (61260-1). The acoustic measurements have been done in the range of 20 Hz to 20 kHz and the analysis in octave bands.

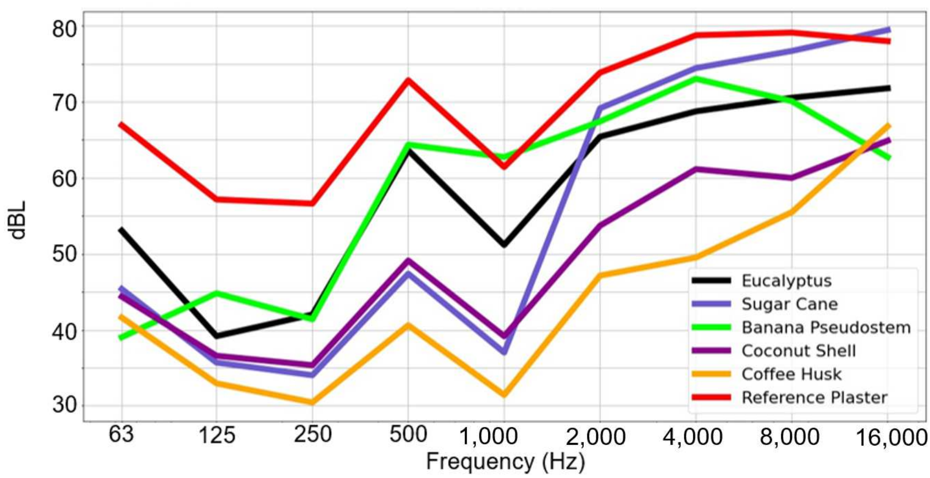

Figure 4. coustic behaviour of the studied materials.

In the range of frequencies considered as 'low', the eucalyptus (54 dBL) followed by banana pseudostem (47 dBL) and sugar cane (46 dBL) presented good performance compared with the others, being the reference 67 dBL; in the 'middle' range, the banana pseudostem (70 dBL), sugar cane (69 dBL) and eucalyptus (68 dBL) presented better performance in comparison with the others and being the reference 76 dBL; and finally, in the range of 'high' range of frequencies, the sugar cane (82 dBL) followed by eucalyptus (75 dBL) and banana pseudostem (75 dBL) presented better performance compared with the others, being the reference 83 dBL. The coffee husk and the coconut shell presented lower performance of SIL in the ranges analysed. It can be observed that as a trade-off analysis, the eucalyptus presented the overall best performance considering overall range, and there is considerable difference between the reference compared with the samples proposed in 'low' range. However, in the 'middle' and 'high' range this difference has been reduced.

It was expected to find any acoustic difference in some frequency band correlated to the coffee husk density (Fig. 5). However, the values of insertion loss didn't characterize this difference Consequently, it is necessary to investigate more deeply about it.

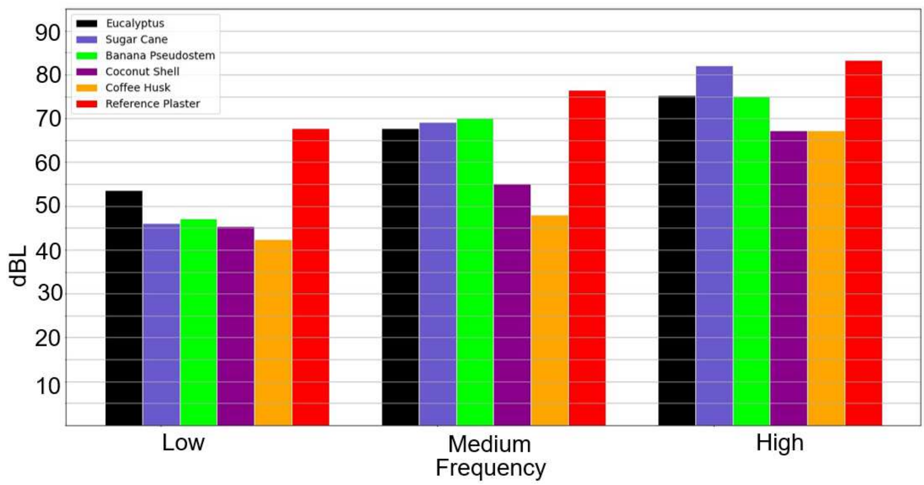

Figure 5. Acoustic behaviour of the studied materials separated in ranges of frequency (low, medium, high frequency).

Summarizing, the eucalyptus shows the best performance in 'low freq' frequencies. the banana pseudosterm was better in 'middle' frequencies and sugar cane in 'high' frequencies. However, in a trade-off analysis, if the interest is 'low' and 'middle' frequencies, the eucalyptus and banana pseudosterm could be considered as good candidates, and if the interest is 'high' range, definitely the sugar cane could be a good candidate.

CONCLUSIONS

Physical properties of the lignocellulosic materials have been measured, and the results show that for the thickness property, the high value belongs to eucalyptus, followed by sugar cane and banana pseudosterm; for the property of density, the high value belongs to coffee husk, followed by eucalyptus and sugar cane, and finally for the property of porosity, the high value belongs to banana pseudosterm, followed by eucalyptus and sugar cane. Using the insertion loss acoustic analysis, explored in results and discussion section, the eucalyptus has had better performance, followed by banana pseudostem and sugar cane in 'low' and 'middle' range of frequencies, and the sugar cane has had better performance, followed by eucalyptus and banana pseudosterm. In spite of having a high value of density, the coffee husky didn't show any interesting insertion loss acoustic performance, and needs to be studied more deeply. However, the other materials of eucalyptus, banana pseudosterm and sugar cane have shown interesting acoustic characteristics. The next step is proposed to improve the acoustic facility in order to explore with two or three microphones, which will permit data for acoustic absorption coefficient and transmission loss studies.

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