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INVESTIGATION OF IMPACT NOISE INSULATION PANELS MADE OF LATEX AND REGIONAL FIBERS

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Abstract. *Impact sounds, such as those created by footsteps, punching machines and presses or the dropping of an object or the moving of furniture, can be a source of great annoyance in residential and working buildings. Materials with resilient properties, such as vinyl or carpet, or floating floors, consisting of a slab of rigid material supported on a flexible material, are normally used in order to obtain good control of impact noise. Thus, the characteristics and level of impact noise generated between adjacent spaces depend on the object striking the floor, the structure of the floor assembly, and floor covering. An investigation of the impact sound insulation performances of different latex materials that could be used as floor coverings in buildings to reduce impact noise is presented in this paper. The latex materials were compound with wood and açai residues to various different thicknesses. A reverberation chamber was used to perform impact noise insulation measurements, adopting the methodology of Insertion Loss. All the results obtained to characterize the acoustical properties of panels have been discussed in detail.*

Keywords: Impact noise, latex materials, tapping machine, impact insulation, regional fibers.

1. INTRODUCTION

The development of construction techniques to provide acoustic comfort in buildings with multiple floors has been a constant concern in many countries. However, the construction of buildings with low cost and ease of construction shows that it goes against soundproofing studies. Even if little explored in Brazil, the theme has been gaining ground in institutes of education and research, and in private companies, both to generate knowledge and disseminate it in order to catalyze its applications in the construction industry (Ferraz, 2008).

In this sense, according to Long (2006) impact noise insulation of building floors is of great interest to ensure habitability and acoustic healthiness in residential environments. This type of noise is produced by impacts of building elements, such as falling objects, which can generate annoyance in users of adjacent environments.

Studies of floating floor systems using fiberglass insulation as resilient material, for example, was developed by Akkerman (1996), and demonstrate how the problem can be treated with usual materials. The tests, performed in situ, were made on a slab of 120 mm thick. The fiberglass panels, of different densities and thicknesses, were laid under two types of flooring: finished ipe wood floor and finished floor in cement mortar and sand.

Pujolle (1978) lists the main factors that determine the isolation efficiency of noise impact of a floating floor: nature and thickness of the resilient material (the dynamic joint stiffness of the elastic material of a floating floor is inversely proportional to its thickness) and nature of structure and overhead slab. According to Bistafa (2011), for concrete slabs, the normalized impact sound level for frequencies above the critical frequency is independent of the frequency in analysis. Sancho and Senchermes (1982) compare typical curves of impact noise insulation, considering the structural slab without flooring, a floating floor and a combination of floating floor covered with elastic material.

Therefore, in order to follow these lines of studies and promote this research with regional materials, this paper refers to the results of noise measurements to assess the characteristics of impact noise insulation blankets of latex with

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açai and regional wood provided by Pole ProBio, using the reverberation chamber from the Acoustics and Vibration Group (GVA) of the Federal University of Pará (UFPA).

2. STRUCTURAL NOISE

Structural noise is caused by vibrations due to impact and/or dynamic excitations of different natures (periodic excitations), in any component of the building. The building surfaces work as amplifiers of sounds generated by vibration; the impact or vibration cannot generate noises by itself, but if the source is connected to a wall, for example, noise is amplified because of the vibration produced on the wall (Mehta, 1999).

According to Ferraz (2008), the impact is a result of an excitation of short duration which may be repetitive or non-periodic. People walking, dancing or jumping are clear examples of impact noise. Other sources of impact are people practicing basketball, rotating machines with low insulation, pile-driving, bowling, moving of furniture, door slam, etc. Figure 1 shows various sources of noise and forms of propagation throughout the structure.

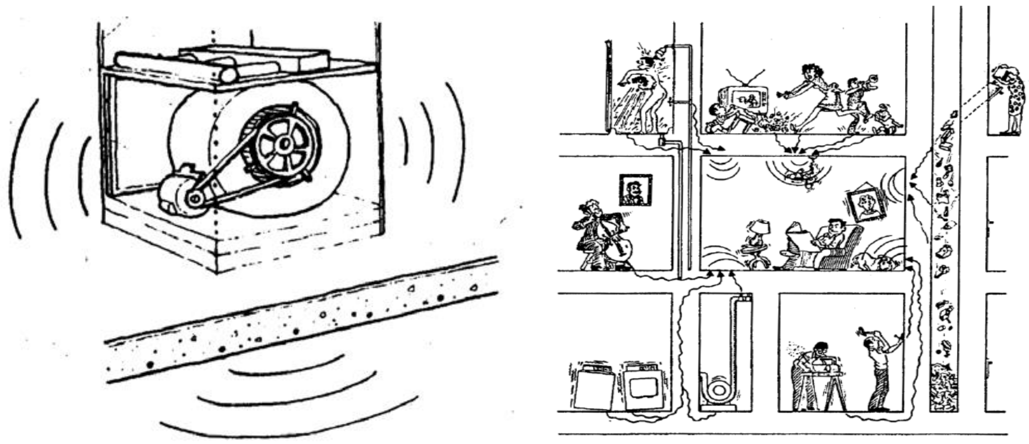

Figure 1. Sources of structural noise and forms of propagation throughout the structure (Mehta, 1999, and Fahy, 1987).

Vibration of floors can be a source of complaints in building structures, particularly in light constructions, such as concrete on forms of steel embedded (Steel Deck), metal or wooden studs and slabs of small thickness.

As described in Sancho and Senchermes (1982), an effective slab for airborne sound insulation may be inappropriate for impact noise insulation purposes. Building floors are often required for actions that cause shock impact noise. Noises propagated through a slab, reach the walls and are transmitted to adjacent environments, as shown in Figure 1. According to Long (2006), floor dynamic excitation effects are not limited to environment receptors located immediately below the source. For example, in fitness centers, with aerobic character, induced vibrations may be perceived in a lateral distance of 30 m from the same slab or 10 floors below to the source.

The commonest attenuator system for impact noise transmission is the floating floor. Such system consists basically on the introduction of a resilient material between the structure (concrete, steel, wood) and the sub-floor (GERGES, 2000). However, it is essential that the resilient element completely isolates the sub-floor and the surface of the floor, not allowing contact with the structure, walls or other rigid elements.

Materials with elastic properties are also commonly used: wood, fibers, cork or low density rubber, bidim OP60, EVA, polyethylene blanket and expanded polystyrene.

2.1 SOUND ENERGY GENERATED BY SURFACES

The sound radiation generated by surfaces must take into consideration the magnitude of structural vibration, its transmission and distribution in relation to the sound audibility, which is radiated to the envelope surface. To predict the sound radiation it is necessary to know the vibration amplitude, frequency and its space distribution.

Figure 2 illustrates a problem of noise generated by surface radiation; this work is described in Fahy (2001). The source introduces mechanical power on the directly excited component. This component dissipates a portion of that power through the cushioning and transfers the remaining energy to the component connected to it, which dissipates a portion of that power internally and radiates the rest into the air. The number of degrees of freedom of the structure may be apparently reduced from hundreds or thousands (of modes) to two, representing the average total time of energy stored in the component.

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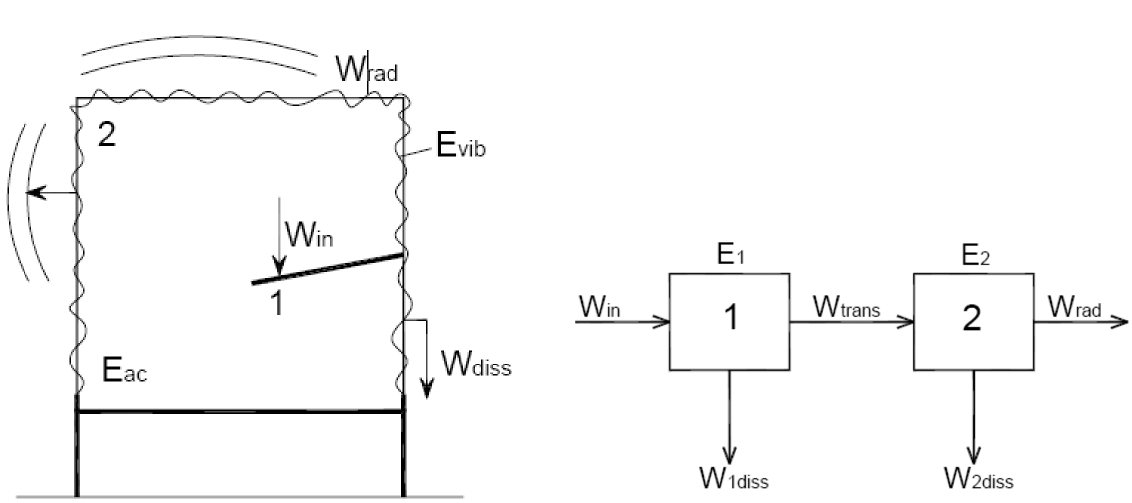

Figure 2. Structural radiation model (Fahy, 1987).

In Figure 2, W_{in} is the introduced power; W_{diss} is the dissipated power; W_{rad} is the radiated power; W_{rad} is vibrating energy; and E_{ac} is the acoustic energy. It is desirable to know not only the radiated power, but also the relation between the structural vibrations and its power. The radiated power (W_{rad}) of a structure with a surface area S, and the radiation surface average velocity υ, is given by:

$$W_{rad} = \rho_0 \cdot c_0 \cdot v^2 \cdot S \cdot \sigma_{rad} \tag{1}$$

where σ_{rad} is the radiation efficiency. Equation 1 can be rewritten logarithmically by:

$$10\text{Log}\,\sigma_{rad} = L_w - L_v + 10\text{Log}\frac{\bar{A}}{4S} \tag{2}$$

$\bar{A}$ being the equivalent absorption area, L_w the sound power level, and L_v the speed level. According to Bistafa (2011), for concrete slabs, the normalized impact sound level for frequencies above the critical frequency is independent of the frequency analysis, according to the equation:

$$L_{nband} = -30\log t + \Delta L_{band} - 54\ dB \tag{3}$$

where ΔL_{band} = -1.5 dB for octave bands, ΔL = -6.5 dB for third octave bands, and t is the thickness of the slab, in meters. This equation indicates that doubling the slab thickness the sound level radiated into the room below is reduced by 9 dB. However, in practice, this alternative is not adopted, since it involves high costs and introduces structural problems in the building (BISTAFA, 2011).

The use of blankets as floating floor has being widely studied. Some simplified physical models of the system are designed for floating floors (Fig. 3). This system is understood as a mass-spring-damper system, where the mass (m) is characterized by the surface density of the sub-floor in kg/m², the spring is characterized by the dynamic stiffness of the isolator (s') in N/m³, and the damping is referred to by the internal friction of the resilient material or insulator in N.s/m³.

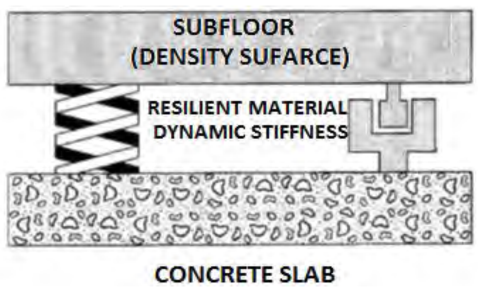

Figure 3. Physical model of a floating floor (Bistafa, 2011).

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The experimental method for determining the dynamic stiffness of the isolator and natural frequency is found on the ISO 9052 standard. At frequencies below the resonant frequency, the slab and the floating floor move jointly and in phase. In this frequency range, improving the insulation is not as expressive, since the floating floor adds a relatively small mass to the structural slab. In the vicinity of the natural frequency, the floating floor has less favorable performance when compared to the slabs without floating floor, since the insulation depends on the internal damping of the insulating material. According to Bistafa (2011) and Sancho and Senchermes (1982), the reduction of the normalized impact sound level, refers to the difference between the sound levels measured in the reception room, which shows that the decrease in sound pressure levels are higher for higher frequencies. Akkerman (1996) varied density and thickness of fiberglass insulation samples, noting that thicker and lower density fiberglass samples produce the best results of noise impact reduction (especially for high frequencies).

3. EXPERIMENTAL SETUP

The ISO 140-7 standard describes field measurements of impact sound insulation of floors, using a standard tapping machine, specified in Annex A of the referred standard.

The quality of noise impact mitigation of a blanket sample, between two vertically adjacent environments, can be evaluated by performing sound measurements in the lower floor of a standardized impact noise transmission system. Procedures required by ISO 140-7 for measuring impact noise isolation indices are:

- The noise source room will be the one with the tapping machine and, below this, will be the receiving room, where the microphones should be positioned;
- Four microphone positions shall be analyzed in the receiving room. For each measuring position four different positions of the tapping machine shall be considered, with three excitations for each test;
- The impact machine should be at least 0.5 m from the walls;
- Microphone and tapping machine positions must have a minimum distance of 1 m from each other;
- The background noise level in the receiving room shall be measured; all characteristics of the impact machine must be in accordance with ISO 140-7.

The sound pressure level of the different microphone positions shall be the logarithmic average energy for all positions of the tapping machine, i.e.:

$$L_t = 10 \log\left(\frac{1}{n}\sum_{j=1}^{n} 10^{Lj/10}\right) \qquad (4)$$

According to ISO 140-7, the insulation characteristics of horizontal building elements must be expressed in terms of the Impact Sound Pressure Level, L_i (Impact Noise Level). This is defined as the average sound pressure level for a certain frequency, measured in the source room when the horizontal element is excited by a standard source. The Normalized Impact Noise Level, L_n, is defined as:

$$L_n = L_i + 10\text{Log}\frac{\overline{A}}{A_0} \qquad (5)$$

where $\overline{A}$ is the equivalent absorption area of the receiving room [m²] and A_0 is the reference area whose value is 10 m². Alternatively, it may be used the Standardized impact noise level L_{nT}, as a function of the reverberation time as:

$$L_{nT} = L_i + 10\text{Log}\frac{T}{T_0} \qquad (6)$$

where T is the reverberation time of the receiving room [s] and T_o is the reference reverberation time of 0.5 s. It is relevant to note that in some cases it is necessary to perform a correction due to the background noise level, which should be at least 6 dB (and preferably more than 10 dB) below the total signal level. If the difference is between 6 and 10 dB, the correction shall be applied in accordance to the standard.

According to Annex A of ISO 140-7, the tapping machine should contain five aligned weights. The distance between the support center of the tapping machine and the center of the weights must be at least 100 mm. Each weight, which impacts on the floor, must have an effective mass of 500 g and allow a free fall of 40 mm of height, with a vertical velocity of 0.033 m/s.

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Thus, experimental acoustic measurements to assess the characteristics of impact noise insulation blankets made of latex mixed with açaí and wood residues provided by Pólo ProBio were performed in this study, using the reverberation chamber of the GVA/UFPA.

3.1 Samples provided

Table 1. Samples composition.

Materials	Type 1 (2 mm)		Type 1 (5 mm)		Type 2	
	PHR	Weight (Kg)	PHR	Weight (Kg)	PHR	Weight (Kg)
Natural rubber	100.0	1.155	100.0	1.352	100.0	1.352
Micro particles of wood	-	-	-	-	61.5	0.832
Açaí waste ash	24.8	0.286	24.8	0.335	24.8	0.335
Açaí waste	69.2	0.798	69.2	0.935	-	-
Total	194.0	2.239	194.0	2.822	186.3	2.619

Samples of latex blankets mixed with regional fibers (açaí), with different thicknesses, were provided to perform sound insulation measurements. Figure 4 shows samples of type 1, provided with thicknesses of 2 and 5 mm (three samples each) for impact noise insulation measurements: natural rubber, manufactured with pre-vulcanized latex, micro particles of wood, açaí waste ash, and açaí waste. Figure 5 shows samples of type 2, provided with a thickness of 2 mm (three samples) for impact noise insulation measurements: natural rubber manufactured with pre-vulcanized latex, açaí waste ash, and açaí waste. Detailed specifications about samples composition are shown in Tab. 1.

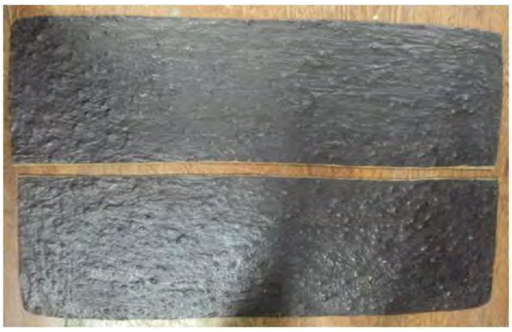

Figure 4. Type 1 blanket samples.

Figure 5. Type 2 blanket sample.

3.2 Measuring Equipment

The reverberation chamber of the GVA/UFPA was used to perform impact sound insulation measurements, as can be seen in Figure 6. This chamber has the function of promoting a sound field consisting of multiple sound waves, which, ideally, would arrive at the microphone from all directions of space, with equal probability. Furthermore, it is observed the presence of a large number of sound diffuser elements positioned on the ceiling, in order to provide further reverberation.

Figure 6. Reverberation chamber (receiving room).

Table 2. Reverberation chamber data.

Scaled Reverberation Chamber Dimensions	
Scale (1:6)	
Height (m)	0.80
Length (m)	1.20
Width (m)	1.00
Total Area (m^2)	5.92
Volume (m^3)	0.96

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The reverberation chamber does not meet the standard requirements, therefore its acoustic modes were calculated to know the trust band of the chamber using the following equation:

$$\boldsymbol{f} = \frac{c_0}{2}\sqrt{\left(\frac{n_x}{L_x}\right)^2 + \left(\frac{n_y}{L_y}\right)^2 + \left(\frac{n_z}{L_z}\right)^2} \tag{7}$$

where L_x, L_y and L_z are the chamber length, width and height, and n_x, n_y and n_z are non-negative integers. Through this equation were obtained as the first three results 145, 174 and 218 Hz respectively.

Analyzing these acoustic modes it was considered that reliable results are generated at frequencies above to 300 Hz, since the use of frequencies below to 300 Hz might match with the first acoustic modes of the reverberation chamber, accumulating errors to the results.

Measurements were based on the methodology of "Insertion Loss", which is a comparison between two measurements, with and without the presence of the element under study. For this, it was used the following equipment:

Table 3. Measuring Equipment.

Four channels Signal Analyzer Brüel & Kjaer, type 3560C – *Pulse*. 
Diffuse Field Microphone, Brüel & Kjaer, type 4942. 
Microphone Calibrator, Brüel & Kjaer, type 4231. 
Laptop Toshiba, type P25 – *Satellite* with *Labshop-view software* to control *Pulse* and manipulate the results. 
Tapping Machine Brüel & Kjaer, type 3207. 

The signal analyzer Type 3560C (Pulse) is a portable data acquisition system, with a control module that operates communications through the computer, and an input and output module that controls data input. The microphone is also connected to the Pulse analyzer. The diffuse field microphone is also known as random incidence microphone, for being assigned to provide a flat frequency response to signals received from all directions. This microphone was attached to a tripod and positioned randomly in various positions inside of the chamber (respecting a minimum distance from the walls of the chamber) in order to obtain a final response from a spatial and temporal average of the measured pressure noise level inside the chamber (see Fig. 7B). The noise source was the Tapping Machine positioned on top of the chamber (see Fig. 7A). This source is able to produce a standard impact noise from the use of a set of steel rollers which

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are lifted and released to drop, impacting the surface on which the machine is supported (here, the roof of the chamber). Within the chamber, the microphone records the sound pressure level generated, in third octave frequency bands.

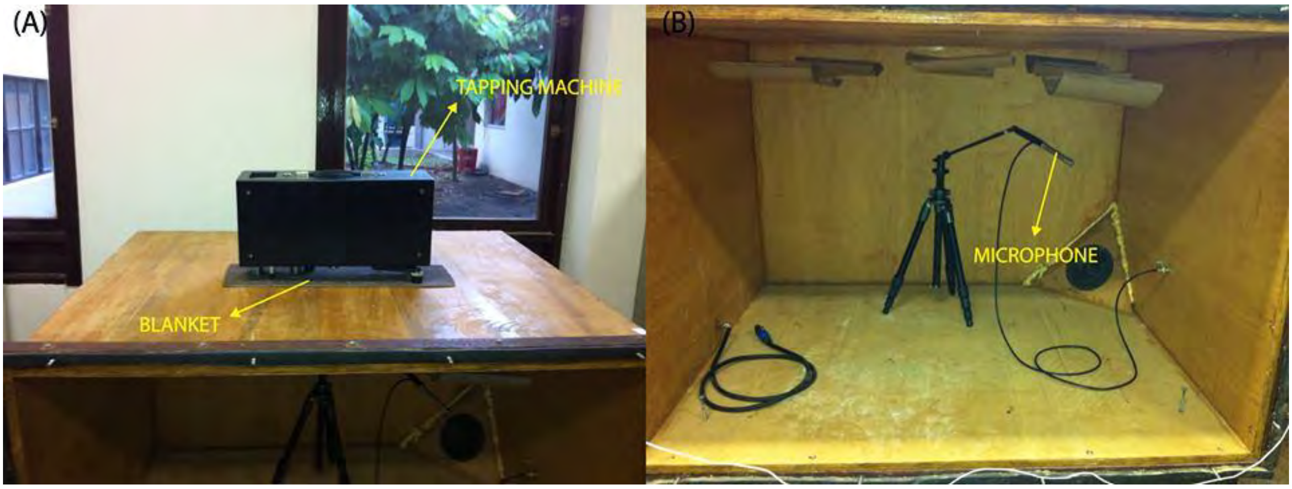

Figure 7. (A) Tapping Machine and Blanket Position. (B) Microphone.

4. RESULTS

Measurements were performed for each sample, which were positioned between the top surface reverberation chamber and striking cylinders in order to cushion impact, allowing the inference of noise reduction inside the chamber by comparison with levels previously obtained, without the presence of the samples (insertion loss). Next, the results of reducing impact noise for each of the samples provided are presented.

Figure 8 shows the sound pressure levels inside the chamber obtained in dB (ordinate) versus frequency in Hz (abscissa) corresponding to the average values measured for three samples of Type 1 (with a thickness of 5 mm).

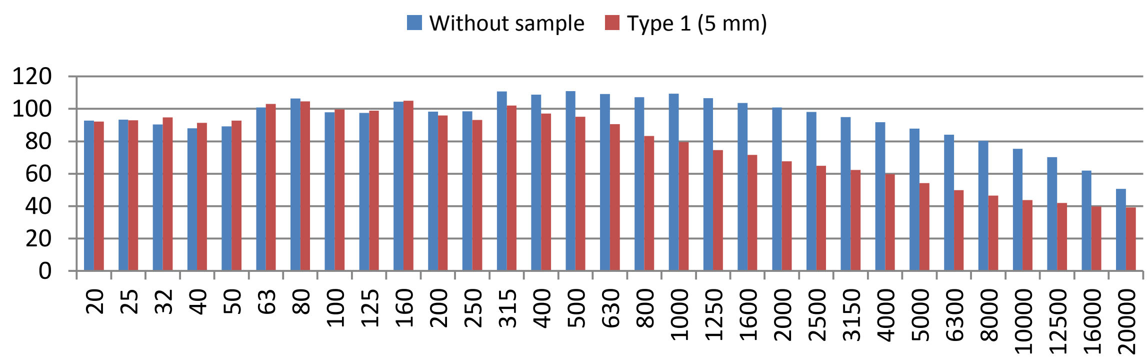

Figure 8. Comparison of sound pressure levels inside the chamber with and without panel Type 1, with thickness of 5 mm.

The level reduction is shown in Figure 9, which corresponds to the average values measured for three samples of Type 1 (with a thickness of 5 mm).

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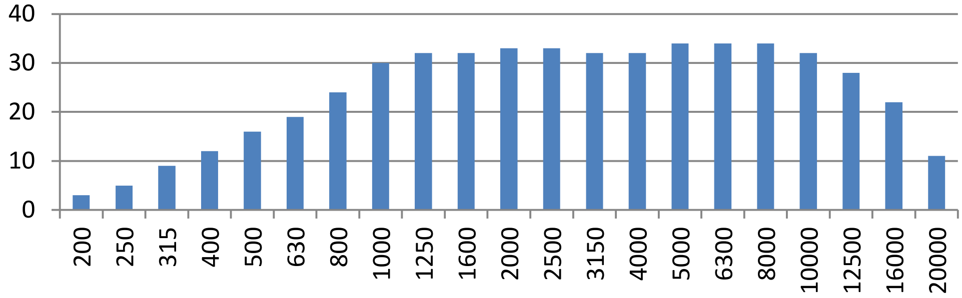

Figure 9. Impact noise reduction for sample panel Type 1, with thickness of 5 mm.

It can be seen that all the tested samples showed significant results above 1.0 kHz. However, sample Type 1 in the configuration of greatest thickness, was able to promote impact noise level reduction above 10 dB above 400 Hz, and for this case, it was observed the greatest impact noise reduction, of the order of 35 dB between 1.25 and 10 kHz (see Figure 9). According to Akkerman (1996), results obtained for fiberglass insulation are between 28 dB and 42 dB for this frequency range, suggesting a good agreement for noise impact mitigation.

A Similar comparison was performed to the other samples. Figure 10 shows the sound pressure levels inside the chamber, corresponding to the average values measured for three samples of Type 1 (with a thickness of 2 mm).

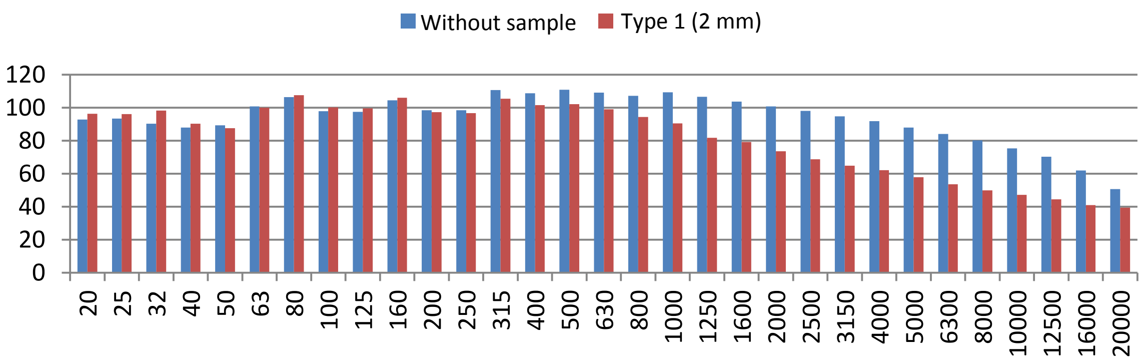

Figure 10. Comparison of sound pressure levels inside the chamber, with and without the presence of panel Type 1, with thickness of 2 mm.

From this result, the reduction of levels is shown in Figure 11, which corresponds to the average values measured for three Type 1 samples (with a thickness of 2 mm).

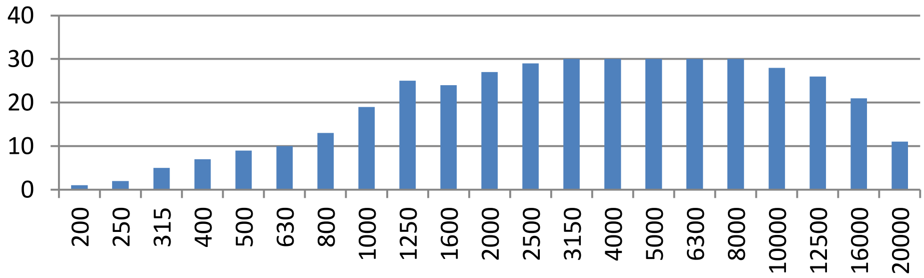

Figure 11. Impact noise reduction for sample panel Type 1, with thickness of 2 mm.

Even in thinner configuration, type 1 samples still show significant reduction of impact noise levels, as it can be seen in Figure 11. In this figure, it is observed that a 10 dB reduction on impact noise levels was achieved in the frequency band of 630 Hz, and maximum values of the order of 30 dB.

Results for sample type 2 are shown in Figure 12, corresponding to the average values measured for three samples of this type (with a thickness of 2 mm).

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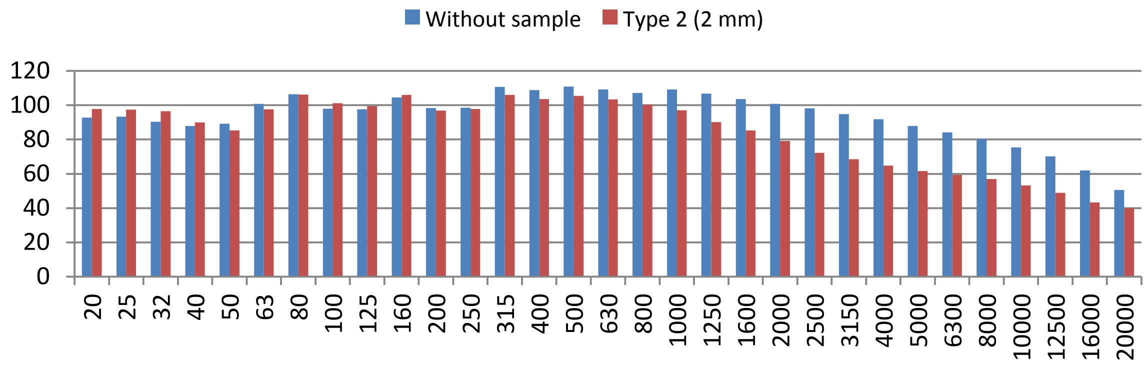

Figure 12. Comparison of sound pressure levels inside the chamber with and without panel Type 2, with thickness of 2 mm.

The reduction levels for this panel are shown in Figure 13, which corresponds to the average values measured for three Type 2 samples (with a thickness of 2 mm).

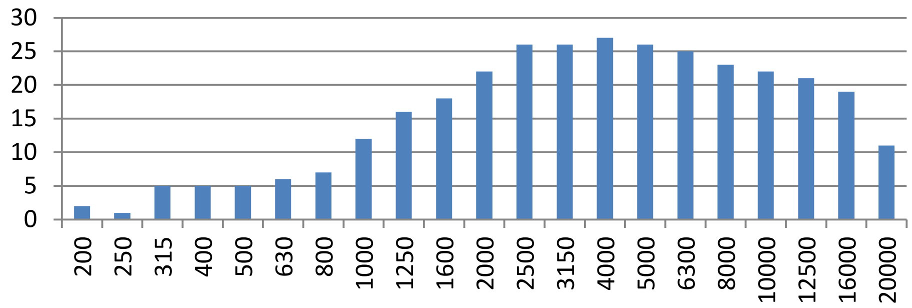

Figure 13. Impact noise reduction for sample panel Type 2, with thickness of 2 mm.

From Figure 13, it can be seen that results were less significant, but still interesting. Sample Type 2 showed a reduction of impact noise levels higher than 10 dB above 1.0 kHz. Also, it showed impact noise level reductions above 25 dB between 2.5 and 5.0 kHz (see Fig. 13).

5. CONCLUSION

In this study, it was possible to prove the potential of the newly developed materials in promoting impact noise reduction, from the comparison between results of impact noise generated by a tapping machine, directly impacting the roof of a scaled reverberation chamber (1:6) and impacting on one of the samples, which have the characteristic of absorbing the impact energy, thereby reducing noise produced within the reverberation chamber.

As expected, and in accordance to Akkerman (1996) and Ferraz (2008), it was possible to observe the best results for the samples with higher thickness, with impact noise level reductions around 35 dB for a wide range of frequencies of great interest to the field of buildings acoustics. Even samples with smaller thicknesses allowed one to obtain level reductions above 25 dB.

Thus, it is considered that the materials tested showed interesting properties for reducing impact noise, which opens the opportunity for further research, in order to allow applications of these materials in construction systems, such as floating floors systems, which are used to promote impact noise insulation between vertically adjacent units in buildings.

Finally, the properties of reducing impact noise observed in the materials tested are considered highly relevant at the present time, in view of the new Brazilian standard NBR 15.575, which requires, among other aspects, a minimum impact noise insulation level in buildings, where the materials investigated here are likely to have direct application.

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