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Placas de isolamento térmico e acústico a partir de biomassa de microalgas, poli-β-hidroxibutirato e lã de vidro

Thermal and acoustic insulation boards from microalgae biomass, poly-β-hydroxybutyrate and glass wool

Placas de aislamiento térmico y acústico de biomasa de microalgas, poli-β-hidroxibutirato y lana de vidrio

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Resumo

Entre as muitas funções que um material de construção precisa ter, destacam-se suas funções de isolamento. Este tipo de material atua diminuindo a condução de calor/som no ambiente.

Nesse contexto, os bio-isolantes têm recebido uma atenção crescente devido ao seu desempenho e ao uso de materiais de isolamento sustentáveis/naturais. Este estudo foi realizado para avaliar o desempenho térmico e acústico de placas de base biológica fabricadas a partir da biomassa de *Spirulina*, poli-β-hidroxibutirato bacteriano (PHB) e lã de vidro. As placas foram fabricadas sob compressão aquecida em diferentes proporções: 33,33% de lã de vidro, 33,33% de PHB e 33,33% de biomassa de *Spirulina* (Placa A); 20% de lã de vidro, 40% de PHB e 40% de *Spirulina* (Placa B); 40% de lã de vidro, 40% de PHB e 20% de *Spirulina* (Placa C); e 40% de lã de vidro, 20% de PHB e 40% de *Spirulina* (Placa D). As placas A e B apresentaram menor condutividade térmica (0,09 W m^{-1} K^{-1}) em comparação aos materiais isolantes tradicionais, como gesso puro (0,44 W m^{-1} K^{-1}) e tijolo isolante de caulim (0,08-0,19 W m^{-1} K^{-1}). A placa D apresentou o maior coeficiente de absorção sonora de ~ 1600 Hz em comparação com outros isoladores de base biológica na mesma frequência, como fibra não tecida à base de polipropileno e fibra de folha de chá com a mesma espessura. Para o coeficiente de redução de ruído, a placa B apresentou melhores resultados que o concreto. Portanto, as placas A e B são adequadas como isolantes térmicos, enquanto as placas B e D são adequadas como isolantes acústicos. Para aplicação simultânea como isolante térmico e acústico, a placa B é a melhor escolha entre todas as placas.

Palavras-chave: *Spirulina*; condutividade térmica; coeficiente de absorção sonora; coeficiente de redução sonora; construções sustentáveis.

Abstract

Among the many functions that a building material needs to have, its insulation functions stand out. This type of materials acts by decreasing the conduction of heat/sound in to the environment. In this context, bio-insulations have been receiving an increasing attention due to its performance and the use of sustainable/naturals insulation materials. This study was conducted to evaluate the thermal and acoustic performance of bio-based boards made from the biomass of *Spirulina*, bacterial poly-β-hydroxybutyrate (PHB), and glass wool. The boards were manufactured under heated compression in different proportions: 33.33% glass wool, 33.33% PHB, and 33.33% *Spirulina* biomass (Board A); 20% glass wool, 40% PHB, and 40% *Spirulina* (Board B); 40% glass wool, 40% PHB, and 20% *Spirulina* (Board C); and 40% glass wool, 20% PHB, and 40% *Spirulina* (Board D). Boards A and B showed lower thermal conductivity (0.09 W m^{-1} K^{-1}) compared to traditional insulating materials, such as gypsum neat (0.44 W m^{-1} K^{-1}) and Kaolin insulating firebrick (0.08–0.19 W m^{-1} K^{-1}). Board D showed the highest sound absorption coefficient of ~1600 Hz compared to other bio-based insulators at the same frequency, such as polypropylene based non-woven fiber and tea-leaf-fiber with the same thickness. For the noise reduction coefficient, board B showed better results than concrete. Thus, boards A and B are suitable as thermal insulators, while boards B and D are suitable as sound insulators. For simultaneous application as a thermal and sound insulator, board B is the best choice among all boards.

Keywords: *Spirulina*; thermal conductivity; sound absorption coefficient; noise reduction coefficient; green building.

Resumen

Entre las muchas funciones que debe tener un material de construcción, destacan sus funciones de aislamiento. Este tipo de materiales actúa disminuyendo la conducción de calor/sonido hacia el medio ambiente. En este contexto, los bio-aislamientos han recibido una atención creciente debido a su desempeño y al uso de materiales de aislamiento sostenibles/naturales. Este estudio se realizó para evaluar el rendimiento térmico y acústico de placas de base biológica hechos de biomasa de *Spirulina*, poli-β-hidroxibutirato bacteriano (PHB) y lana de vidrio. Las placas se fabricaron con compresión calentada en diferentes proporciones: 33.33% de lana de vidrio, 33.33% de PHB y 33.33% de biomasa de *Spirulina* (Placa A); 20% lana de vidrio, 40% PHB y 40% *Spirulina* (Placa B); 40% lana de vidrio, 40% PHB y 20% *Spirulina* (Placa C); y 40% de lana de vidrio, 20% de PHB y 40% de *Spirulina* (Placa D). Las placas A y B mostraron una conductividad térmica más baja (0.09 W m^{-1} K^{-1}) en comparación con los materiales aislantes tradicionales, como yeso puro (0.44 W m^{-1} K^{-1}) y ladrillo aislante de caolín (0.08–0.19 W m^{-1} K^{-1}). La placa D mostró el coeficiente de absorción acústica más alto de ~ 1600 Hz en comparación con otros aisladores de base biológica a la misma frecuencia, como fibra no tejida a base de polipropileno y fibra de hoja de té con el mismo grosor. Para el coeficiente de reducción de ruido, el tablero B mostró mejores resultados que el concreto. Por lo tanto, las placas A y B son adecuadas como aislantes térmicos, mientras que las placas B y D son adecuadas como aislantes acústicos. Para la aplicación simultánea como aislante térmico y acústico, la placa B es la mejor opción entre todas las placas.

Palabras clave: *Spirulina*; conductividad térmica; coeficiente de absorción acústica; coeficiente de reducción acústica; construcciones sostenibles.

1. Introduction

Among the many functions that a building material needs to have, its insulation functions stand out. Insulation is a fundamental parameter in energy performances of a building, where high-performance can significantly reduce heating and cooling consumption. However, in relation to insulation, the building materials have more than a thermal function, they may also present an acoustic role. Some materials can fulfill both of these desired capabilities. Within this theme, much has been said about green buildings in recent years, these buildings design focus on reducing energy use and improved use of sustainable/natural materials instead of mineral ones (e.g. fiberglass or rock fibers) (Chabriac et al. 2016).

According to Liu et al. (2017) with the development of society and people's ecological awareness, a sustainable and healthy indoor environment is increasingly attracting the attention of the public. In this context, bio-insulations have been receiving an increasing attention, obtaining a very good progress in the past years. There is still a lot of work to be done, although, it is firmly believed that bio-insulations can play an important role in the building sector in future.

Studies into the use of sustainable/natural insulation materials as a replacement for mineral ones have already developed low environmental impact structures using different types of biomass; these include hemp, sunflower bark, sunflower pith, flax, straw bale, wood fiber and others (Chabriac et al. 2016; Liu et al. 2017; Volf et al. 2015). Another attractive strand is investing on composite materials using recyclable, raw materials with a commercial binder (Binici et al. 2016; Yang et al. 2003; Yang et al. 2004). It is important to highlight that there are currently no studies that have carried out the manufacture of insulators using microalgae biomass.

Microalgae are photosynthetic microorganisms that use light and carbon dioxide to grow and generate biomass, which can be converted into various bioproducts. Among the possibilities of obtaining natural materials, microalgae stand out as a renewable source of organic matter. With higher growth rates and higher CO_2 fixation than terrestrial plants, these microorganisms are capable of producing various secondary metabolites according to its growth medium. One of these substances is the poly-β-hydroxybutyrate (PHB), which presents high biodegradability and thermoplasticity, making it a potential target for application in diversified areas, such as a binder for insulations in civil construction (Costa & Morais, 2008; Sharma & Mallick, 2005).

Along with the ecological appeal, recycling of building materials has gained increasing focus in many areas of science. Construction and demolition activities are a major source of waste; their share varies between 13% and 40% of the total solid waste generated, depending on the country (Yuan & Shen, 2011). According toVäntsi and Kärki (2015) mineral wool is commonly used in building insulation, accounting for about 60% of the total insulation product market. Besides, this material is often considered difficult to recycle, due to its few applications, and is thus disposed in landfill. Among the materials of construction and demolition that can be recycled, glass wool stands out.

Considering microalgae fast growing, abundance, the potential reduction of carbon footprint and the production of PHB, allied with the recycling of glass wool, the aim of this work was to evaluate the thermal and acoustic performances of a bio-based material made from *Spirulina* biomass, bacterial PHB and glass wool, verifying its application as a possible acoustic and thermal insulation in buildings.

2. Metodologia

2.1 *Microorganism and cultivation media*

The used microorganism in this work was *Spirulina* sp. LEB-18 (Cyanobacteria, Oscillatoriales), strand isolated from the Mangueira Lagoon in Santa Vitória do Palmar, Southern Brazil (33°30’13”S; 53°08’59”W). Zarrouk medium was used for the maintenance and cultivation of the microalgae (Morais & Costa, 2007; Zarrouk, 1966).

2.2 *Manufacture of insulation boards*

Insulation boards were produced using bacterial PHB mix (Yic-Vic Chemical Products - Hong Kong/China), microalgal biomass and glass wool. The mixture was heated in electric sheet, inside steel mold at 280 °C and homogenized manually. Afterwards, the mixture was transferred to a 60 mm x 40 mm metal die and pressed with a manual hydraulic press (MARCON Ind. Ltda. - Palmital/Brazil), producing rectangular plates of 60 mm x 40 mm, adapting the methodology used by Evon et al. (2014). Boards with the same proportion of constituents were made to test different conditions of pressure in order to obtain the best condition for board formation. Boards with different concentrations of constituents were made in order to evaluate and obtain the best balance between thermal and acoustic insulation efficiency.

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Pressures of 245 kgf cm^{-2}, 305 kgf cm^{-2} and 365 kgf cm^{-2} were applied for compressibility evaluation of the board, with temperature and pressing time held constant at 280 °C and 40 s respectively. After pressing the boards, their thickness were determined by pachymeter.

2.3 *Hardness*

The hardness Brinell test was performed in triplicate on a Brinell Pantec test machine (DHB-3000 – Beijing/China) with a 10 mm metal ball applying a tension of 100 kgf. The Brinell hardness coefficient (*HB*) was measured from equation 1:

$$HB = 0.102\frac{2P}{\pi D\,(D\sqrt{D^2 - d^2})} \qquad \textit{(equation 1)}$$

Where *HB* is the hardness Brinell (kgf mm^{-2}), *P* is the pressure applied on board (N), *D* is the diameter sphere (mm) and *d* is the diameter of the orifice formed on board (mm).

2.4 *Thermal insulance efficiency*

In order to evaluate the thermal insulation capacity of the boards, its thermal conductivity coefficient was determined using the C-Therm TCI thermal conductivity analyzer (C-Therm Technologies – New Brunswick/Canada) which provided the thermal conductivity values for each sample at 23 °C. The method used follows the procedure established by ASTM D7984 (American Society for Testing and Materials, 2016).

2.5 *Sound insulance efficiency*

Determination of the sound absorption coefficient for the samples was performed from impedance tube measurements using the transfer function method with two microphones. This procedure followed the methodology described by ISO 10534-2 (International Organization for Standardization, 1998).

For the evaluation of the noise reduction index, standard procedures were used, as described by ASTM-E1050 (American Society for Materials and Testing, 2006).

3. Results

3.1 *Manufacture of insulation boards*

Using the same proportion of constituents, a pressure of 250 kgf cm^{-2} generated a 9.5 mm thick board. For pressures of 305 kgf cm^{-2} and 365 kgf cm^{-2}, 9.2 mm thick boards were

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obtained. As no variation on the thickness of the boards were identified under the amplification of applied pressure of 305 to 365 kgf cm^{-2} it was established that the maximum compressibility of the board can be achieved with the use of 305 kgf cm^{-2} of pressure.

The boards produced as described on item 2.1 presented visual differences in coloration and crumbling (Figure 1). The crumbling effect may be associated to the higher concentrations of glass wool in the board (Boards C and D). On the other hand, the increasing in PHB as well as the biomass implied in lower glass wool concentration, which could solve this problem (Board B). Even board A, made of the same proportion of constituents showed little problem in this regard. The density and surface density of all boards were also measured as means of comparison (Table 1).

Figure 1. Insulant boards produced with different compositions: 33.33% glass wool, 33.33% PHB and 33.33% biomass (A); 20% glass wool, 40% PHB and 40% biomass (B); 40% glass wool, 40% PHB and 20% biomass (C); 40% glass wool, 20% PHB and 40% biomass (D).

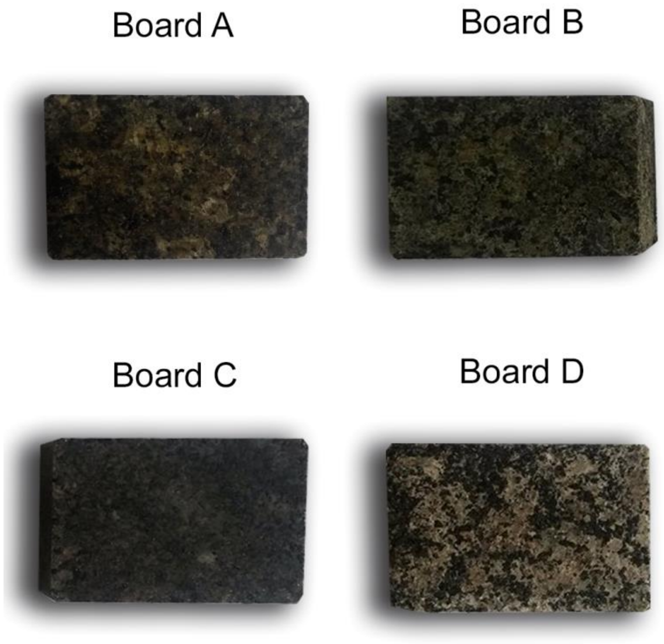


Table 1 Density and superficial density of the produced insulant boards.

Insulant Board	Board A	Board B	Board C	Board D
Density (kg m^{-3})	1439	1357	1521	1300
Superficial density (kg m^{-2})	27.0	27.2	24.3	23.3

Evon et al. (2014) and Panyakaew & Fotios (2011) used smaller pressures in their studies, from 150 to 250 kgf cm^{-2} and 150 kgf cm^{-2}, using a cake generated during biorefiney of sunflower and coconut husk and bagasse, respectively. However, their focus was to evaluate the effect of different densities on thermal insulation efficiency, as well the modulus of elasticity of the product. Evon et al. (2014) noticed more fragile boards using a pressure of 150 kgf cm^{-2}. On the contrary, Panyakaew & Fotios (2011) reached a board that met all of the requirements except for swelling thickness. The manufacture of bio-based board does not only depend on process conditions but also the characteristics of all the constituents. In this study, observing the crumbling of some boards, it was chosen the condition and constitution that provided greater integrity to the board, forming a more rigid structure and less susceptible to breaks, achieved by boards A and B.

3.2 *Hardness*

The result of Brinell hardness obtained for board A, which was elected for this test based on it being the one composed of equal mass of its constituents, was 5.66±0.14 kgf mm^{-2}. The hardness can be defined as the resistance that a material presents to the penetration of an object, that is, a permanent deformation or the risk that it causes on the surface of the material (Tabor, 2000).

Although the hardness obtained for board A can be considered low, it is within the general mean hardness obtained for different species of wood tested by Hirata et al (2001). For example, the wood species *Pinus densiflora*, used in civil construction, has a value for Brinell hardness ranging from 2 to 11 kgf mm^{-2} depending on the age of the wood (Hirata et al. 2001). Thus, the option of external use of these boards can be considered, forming the wall of the building to be insulated and not only its use in the inner lining only as a thermal acoustic insulation.

3.3 *Thermal insulance efficiency*

Boards A and B achieved the lowest thermal conductivity (k) values, 0.0910 W m^{-1} K^{-1} and 0.0908 W m^{-1} K^{-1} respectively. The k value of 0.1602 W m^{-1} K^{-1} for board C was the worst measured, while board D achieved a middle value of 0.1200 W m^{-1} K^{-1}. In order to be considered a thermal insulator, the material needs to have a thermal conductivity lower than 0.1 W m^{-1} K^{-1} (Al-Homoud, 2005) and as the value decreases the better the material capacity to insulate heat. Boards A and B presented potential against heat changes, having thermal conductivity to be used as insulating materials, being better insulators than other bio-based materials even some construct insulating materials being used nowadays (Table 2).

Table 2 Comparison of thermal conductivity (*k*) of our boards with some other bio-based composites and materials used for thermal insulation in building.

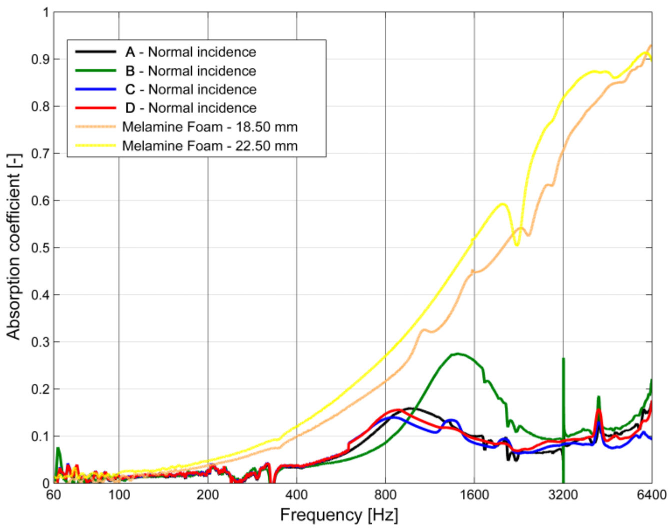
Insulant Material	***k*** **(**W m^{-1} K^{-1}**)**	**Reference**
Board A	0.09	-
Board B	0.09	-
Board C	1.6	-
Board D	1.2	-
Bio-based insulating		
Biorefinery cake of sunflower	0.9-1	[11]
Concrete/coconut (30%)	0.17	[15]
Concrete/durian (30%)	0.18	[15]
Hemi-hydrate gypsum/Date palm fibers (10%)	0.15-0.17	[8]
Sunflower stalk fibers, cotton waste, textile waste, stubble fibers and epoxy	0.16	[6]
Plaster/Barley wheat (25%)	0.29	[5]
Plaster/Wheat fiber (25%)	0.33	[5]
Plaster/Wood shaving (25%)	0.28	[5]
Used construction insulating materials		
Building brick work	0.76	[17]
Gypsum neat	0.44	[8]
Glass wool	0.03-0.04	[20]
Kaolin insulating firebrick	0.08-0.19	[17]
Porcelain	1.38	[17]

Thus, the results demonstrated that the boards produced presented better thermal insulation when compared to other bio-based and constructed insulating materials. Furthermore, the reduction in less glass wool and, consequently, the increasing in concentration of microalgae biomass and PHB revealed better results probably due to a more homogeneous and consist board, knowing that this ingredient causes the crumbling effect.

3.4 *Sound insulance efficiency*

Figure 2 presents the values of sound absorption coefficient for the boards of different composition. The value for a melamine foam of thickness close to that of the boards was also present to comparison, being this one of the most used material for sound absorption (Arenas & Crocker, 2010). All boards have far lower values for the sound absorption coefficient than the melamine foam, which could be related to their high density and low porosity, resulting in high resistivity to the sound flux. However, in the frequency of 1500 Hz board D shows higher coefficient of sound absorption than polypropylene based non-woven fiber and tea-leaf-fiber with the same thickness (Ersoy & Kuçuk, 2009). According to Khan et al. (2017) better results is possible at low binder levels, due mainly to the open porosity of the boards.

Figure 2. Sound absorption of the boards A, B, C and D, performed in impedance tubes at 26 °C with a relative umidity of 60%.



In addition, the sound reduction coefficients of the boards are present in Figure 3, showing that there are small variations in the loss of transmission between samples. This may be explained by the small difference of superficial density of the boards. And when compared to the loss of transmission of materials like concrete (density of 2500 kg m^{-3}) and gypsum plaster (density of 800 kg m^{-3}), which is the best material used for sound insulation in civil construction, board B placed in the middle of both, being a better insulator than concrete (Figure 4).

Figure 3. Noise reduction coefficient of the boards A, B, C and D, performed in impedance tubes at 26 °C with a relative umidity of 60%.

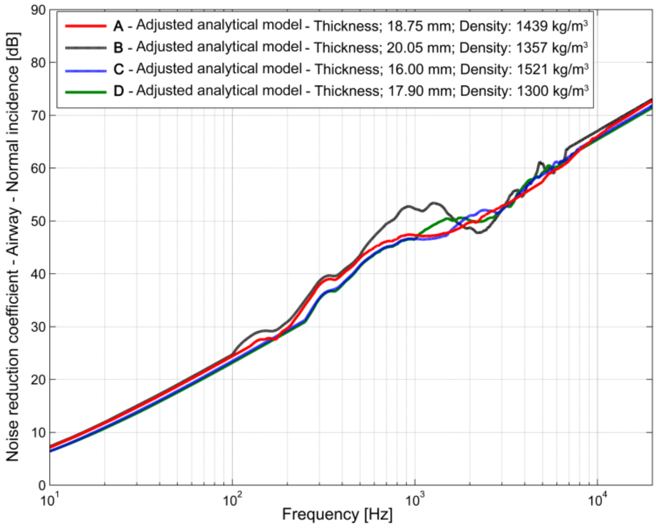
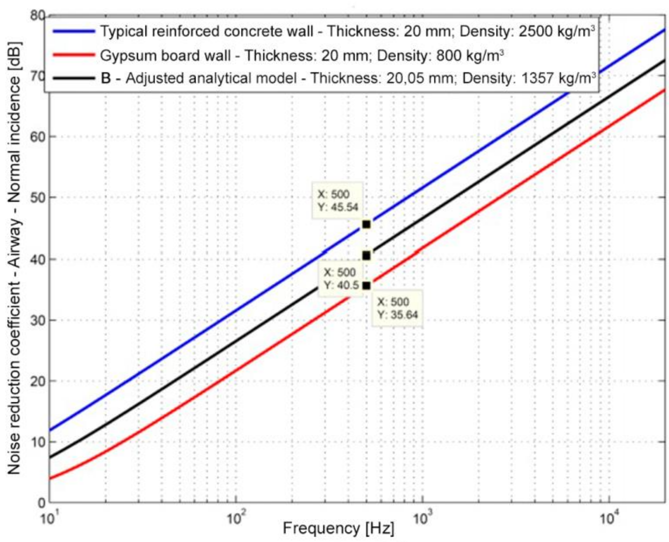


Figure 4. Noise reduction coefficient of the board B, reinforced concrete and gypsum plaster, performed in impedance tubes at 26 °C with a relative umidity of 60%.



4. Conclusion

Boards with thermal and acoustic insulation properties were generated through the heated mixture under pressure of the components. Pressures bigger than 305 kgf cm^{-2} did not change board density, generating a hardness of 5.66±0.14 kgf mm^{-2}. However, different compositions did, originating boards with different states, some more fragile or less dense. Boards A and B presented thermal conductivity of 0.09 W m^{-1} K^{-1}, better than other insulators in literature. The boards achieved similar superficial density, implying similar noise reduction coefficient, being better than concrete, highly applied in civil construction. Board D showed the best sound absorption at 1500 Hz, superior to other composites. All boards have far lower values for the sound absorption coefficient than the melamine foam, which could be related to their high density and low porosity, resulting in high resistivity to the sound flux. Being so, the relation between applied pressure and sound absorption can still be vastly improved as means of increasing the acoustic properties.

These results indicate the boards can be possible applied for insulation on buildings. However, future studies will test different components proportions, along other pressure values, for further enhancement of thermal and acoustic insulation properties.

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