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Building bio-insulation materials based on bamboo powder and bio-binders

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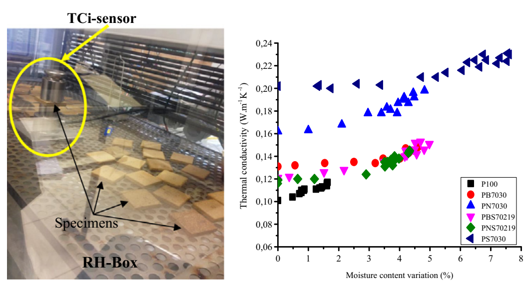
HIGHLIGHTS

- The hygrothermal properties of bamboo particles are studied.
- Novel binders from natural resources are used for building bio-insulation materials.
- Influence of high relative humidity on durability of bamboo particles is investigated.
- Thermal insulation of bio-materials is evaluated under different humidity conditions.

GRAPHICAL ABSTRACT

Thermal conductivity measurement.



Thermal conductivity measurement

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ABSTRACT

Bio-insulating materials are well known to reduce the environmental impact of constructions and are able to regulate the indoor temperature and humidity of buildings. This study investigates the influence of high-absorbing bio-glues based on a protein and lignin compound on moisture transfer and storage as well as on thermal performance of bamboo particleboards. The investigations are based on the moisture buffer value, vapor permeability, isothermal vapor sorption and thermal conductivity. Simultaneously, the mechanical properties and mold growth of these materials, manufactured for the study, are also investigated. The results demonstrate excellent moisture buffer capacity, from 2.13 to 3.26 g/(m^2·%RH). The vapor sorption isotherm results exhibit the materials' high moisture storage, and the vapor permeability behaves like commercial bio-insulating materials. The thermal conductivity of particleboards shows a low value, in accordance with their density and variation in moisture content. In addition, the results indicate mold appearance on the surfaces of specimens after 14 days exposure to 84% relative humidity. Moreover, a comparison of the hygrothermal characterizations between bamboo particleboards and fiberboards (Nguyen et al., 2017) is carefully made to highlight the exceptional features of those bio-boards.

1. Introduction

One of the greatest challenges for future buildings is to reduce energy consumption throughout their lifespan: construction, demolition as well as cooling, heating, air conditioning and

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ventilation during use. One approach to reduce energy use in buildings is to improve the insulation properties of building envelopes [2]. To date, synthetic materials from polymers such as polystyrene and mineral or glass wool have been used as high-quality thermal insulation for building envelopes [3]. However, these materials are costly, consume a great deal of energy to be manufactured and release a large amount of waste in the environment after use. In addition, petroleum-based products will be increasingly exhausted in the future. On the other hand, long time ago, most popular fiberboards, particleboards and wood panels based on natural resources were combined with phenol-formaldehyde (PF), urea-formaldehyde (UF), urea-melamine-formaldehyde (UMF), which were effective glues providing excellent mechanical properties and high water resistance. However, these materials release formaldehyde into the environment, which directly affects indoor air quality and inhabitants. Exposure to formaldehyde present in the air can result in the following health effects: skin irritation, watery eyes, coughing and nausea. Furthermore, prolonged exposure to formaldehyde can cause certain types of cancer such as nasopharyngeal cancer in both humans and animals [4,5]. Formaldehyde emissions from materials are mainly released during manufacturing but they continue to be emitted throughout their life [6]. Therefore, insulating materials are now being thought from natural resources, because they are environmentally friendly, renewable and low cost, and they minimize energy consumption. Natural fibers from different resources are becoming popular and are being used as bio-insulation materials for buildings because they have a low density, a high porous structure, a low environmental impact and low thermal conductivity. In addition, they provide high hygrothermal performance, participate in humidity control and improve indoor air quality [2,7–11].

Novel bio-insulating materials based on natural fibers and bio-adhesive agents from vegetable oil, chitin, lignin or protein [12–14] have been studied by many research groups. However, these materials have drawbacks such as poor water resistance, easy mold appearance, low mechanical properties and weak boundary adhesion that limit their applications. To address these disadvantages, modified bio-glues have been widely studied and reported in recent years. In particular, lignin is often used to modify various proteins including proteins based on wheat gluten [15–19], soybean [13,14,20], fish [21] and protein from maize [22].

Lignin is quite compatible with proteins and reduces the amount of the polar group in proteins, increasing water resistance and mechanical properties. Panels made from natural products are generally used for their thermal properties, but their hydrophilic properties could make their use as buffer materials possible and thus they could contribute to humidity control in buildings.

To date, conventional methods such as heating, cooling and air conditioning have been used to control the humidity level for buildings, inducing high energy consumption. Therefore, one of the passive ways to control humidity consists in using buffering materials, which are able to sorb and desorb humidity when environmental conditions change. Natural fibers seem to be able to act as buffer materials due to their composition: the main components of natural fibers are cellulose, hemi-cellulose and lignin. Their moisture absorption and desorption ability stems from the presence of the hydroxyl (–OH) groups in their macromolecules. However, cellulose is highly crystalline, and thus more difficult for water molecules to access than lignin, which is an amorphous polymer composed of phenolic units [23]. Moreover, natural fibers have a high porous structure, porosity being an important parameter for the moisture sorption phenomenon. Therefore, natural fibers are good candidates for hygrothermal performance of building materials. The hygrothermal properties of building materials are mainly characterized by moisture buffering, isothermal vapor sorption, water vapor permeability and thermal conductivity. Moisture buffering is very important for the comfort of the occupants and for indoor air quality in buildings. These hygroscopic materials can uptake or release moisture to control humidity in buildings and reduce energy consumption by reducing heating and cooling needs [24–27]. In particular, Palumbo et al. report six different bio-based insulating materials: hemp lime (HL), hemp fiber (HF), wood wool (WW) and wood fiber (WF), barley straw-starch (BS) and corn pith-alginate (CA) [28]. The result presented excellent moisture buffer values from 2.3 to 3.0 g/(m^2·%RH) except for CA (approximately 1.9 g/(m^2·%RH), which falls into the "good" category as defined by Rode et al. in the Nordtest project [26]. These materials also showed a vapor resistance factor ranging from 2.4 to 6.5 with the dry cup test method and low thermal conductivity coefficients from 0.038 to 0.064 $W{\cdot}m^{-1}K^{-1}$. Other bio-insulating materials based on different hemp and shive fiber ratios with 20% (w/w) polyester binder were studied [3]. The hygrothermal behavior of these materials showed that they are open to diffusion, with low vapor diffusion resistance ranging from 2.1 to 5.3. The result also showed a narrow range of thermal conductivity, from 0.0399 to 0.05 $W{\cdot}m^{-1}K^{-1}$, in agreement with their densities. To conclude, the bio-materials used for building based on bamboo, straw, hemp, sheep wool, coconut and wood fiber are not only environmentally friendly materials, but also reduce the energy use within buildings [2,12] and provide better thermal comfort for occupants, as well as better health [29]. On the other hand, the different sizes of natural fibers greatly influence the materials properties. For example, influence of flax-shives content and size on the morphology, structure, mechanical, thermal and acoustic properties of fiberboards from casein binder and flax-shaves is investigated [30]. The results show that compressive and flexural stresses at break as well as thermal conductivity of the fiberboards decrease when the fibers content and the size increase. This is due to the use of big aggregates of flax-shives leading to a less compactness of the fiberboards. Additionally, the use of flax-shives leads to increase the acoustic absorption coefficient. The influence of Kraft fiber lengths on reinforced polypropylene composites is also studied [31]. The tensile strength, the young modulus and the impact strength decrease with the increasing fiber length due to a reduced reinforcing efficiency. Moreover, the water absorption amount of different natural fibers is presented in the literature [32]. The water absorption amount of banana fibers is higher than sisal and cork at the same fiber diameters.

In this study, novel bio-insulating particleboards from bamboo powders and different bio-adhesive agents such as bone, nerve and sodium lignosulfonate glues are investigated. The targets are to manufacture and evaluate the hygrothermal performance of these bio-materials for buildings under different relative humidity conditions. The mold appearance on these sensitive materials is also investigated at high humidity. Finally, the hygrothermal properties of these bamboo particleboards are compared to that of the bamboo fiberboards which were reported in our previous study [1].

2. Materials and experiment

2.1. Materials

Bamboo (Bambusa stenostachya) was supplied by the Scientific Research Center for Conservation of Natural Resources, Hochiminh City, Vietnam. The bamboo powder (0.1–0.2 mm in diameter) was crushed from bamboo fibers. Nerve glue is a protein-based adhesive made from cattle nerves. It is a powder soluble in water. Bone glue is a protein-based adhesive made from collagen of bones, sinew and cartilage. It has a granular form and is soluble in water with pH 6.5. Its glass transition temperature (T_g) is about 160 °C [33]. Both glues were supplied by Briançon Inc., France.

Sodium lignosulfonate was purchased from Carl Roth GmbH+ Co. KG Inc., Karlsruhe, Germany. It is in powder form and its miscibility with water at 20 °C is 600 g/l. Its melting point is higher than 130 °C and it has a bulk density at 20 °C of 500 kg/m^3.