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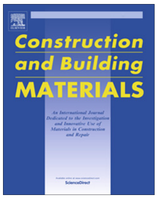

Hygrothermal properties of bio-insulation building materials based on bamboo fibers and bio-glues

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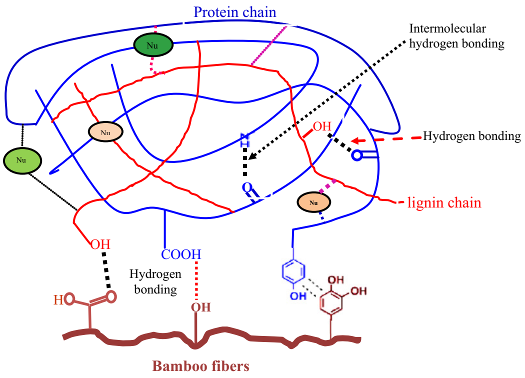
HIGHLIGHTS

- Bamboo fiberboards were manufactured using different bio-glues.
- Hygrothermal properties depend on the glue.
- The fiberboards exhibited 'Excellent' and 'Good' moisture buffer value.
- Relationship between thermal conductivity and moisture content was investigated.

GRAPHICAL ABSTRACT

A model of lignin-protein-bamboo fibers network.



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ABSTRACT

This study focuses on manufacturing by thermo-pressing new low-environmental-impact bio-insulation fiberboards from bamboo fibers and bone glue, modified with sodium lignosulfonate. The aims are to measure moisture buffer value, water vapor permeability, bending properties, thermal conductivity and vapor sorption isotherms of these materials. The moisture buffer values of these materials belong to the "excellent" category, ranging from 2.5 to 3.9 g/(m^2.%RH), higher than the value for bamboo fiberboard without glue (1.7 g/(m^2.%RH). The water vapor diffusion resistance factor ranges from 8 to 17, which is similar with other fiber insulation materials. The bending properties show a significant improvement when 30% (w/w) glue is used, the glue being a mixture between bone and sodium lignosulfonate glues. Moreover, the variation in thermal conductivity of the fiberboards with relative humidity and moisture content is investigated to evaluate the hygrothermal performance of the fiberboards. The results are promising for both thermal insulation and moisture buffering, thus these fiberboards could be used for passive control of indoor environment.

1. Introduction

Indoor air quality is one of the most serious elements for the health of a building's occupants. For example, a high moisture level

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Nomenclature

MBV	moisture buffer capacity, g/(m^2.%RH)	δ	water vapor permeability, (kg/(m.s.Pa))
K	thermal conductivity, (W/(m.K))	d	thickness of the specimen, (m)
ρ	density, (kg/m^3)	μ	water vapor resistance factor, (–)
ΔMC	variation moisture content, (%)	δ_a	water vapor permeability of air, (kg/(m.s.Pa))
g	water vapor flux, (kg/(s.m^2))	d_a	thickness of the air layer, (m)
A	exposed area of the test specimen, (m^2)	W	water vapor permeance, (kg/(m^2.s.Pa))
Δk	variation of thermal conductivity, (%)		

is a risk factor for a building's energy performance, mould growth, and loss of the insulation properties of insulation materials [1–3]. Therefore, improving the environmental quality of buildings is considered a priority issue. A good way to improve their hygrothermal performance consists in using materials with low environmental impact and high moisture-buffering capacity. The capacity of adsorbing and desorbing moisture allows materials to act as a moisture buffer. The moisture buffering of the building can reduce energy used for heating and cooling by decreasing the ventilation rate and improving indoor air quality. The moisture buffering performance of buildings and the amount of moisture uptake and release of materials depend on the material's characteristics, relative humidity and temperature of the environment [4–6]. Recently, bio-materials based on natural fibers such as hemp fiber, flax and straw have been considered pertinent materials because they are renewable, low-carbon materials with good hygric and thermal performance [7,8]. Such materials have high hygroscopicity and may be more useful than conventional building materials. In addition, the hygroscopically complex behavior influences the thermal performance of materials [7].

The hygrothermal properties of different materials have been reported in the literature. Vapor permeability (or vapor diffusion resistance factor) is used to characterize moisture diffusion. For example, wood fiber insulation material shows a water vapor resistance factor (μ-value) of 6, whereas wide-ring wood tangential and narrow-ring wood tangential materials have a μ-value of 34 and 42, respectively [9]. Coir-based materials show a μ-value ranging from 5 to 30 [10]. Moreover, the μ-values of highly hygroscopic materials have also been reported for products based on kenaf (1.2–2.3), sheep wool (1.0–3.0), and recycled cotton (1–2) [10]. Traditional construction materials have permeability properties similar to those of bio-based materials. Expanded polystyrene (EPS) have a μ-value range between 20 and 70 [10]. In another study, wood fiber board (WFB) has μ- value of 10.5 [11]. Wood paneling (WP) and aerated cellular concrete (ACC) show vapor resistance factors ranging from 43 to 514 and from 9.4 to 9.9 respectively [11].

The hygrothermal properties of materials are also evaluated by isothermal vapor sorption. Indeed, the accumulated or equilibrium moisture content in material depends on the ambient relative humidity. This storage capacity is described by the sorption curve of the material (moisture content as a function of relative humidity), determined by weighing the amount of water vapor adsorbed or desorbed under different levels of relative humidity. The sorption isotherms of natural fibers such as jute, flax, coir and hemp [12] and of hemp-based building materials [13,14] are reported in previous researches. The slope of sorption isotherms ($\xi = d_{MC}/d_{RH}$) is often used as an indicator of hygroscopic behavior.

An additional way to evaluate material's hygroscopicity is its moisture buffering capacity. It can be measured by experiment or simulation, as for example, the MBV (moisture buffer value) proposed by Rode et al. in the NORDTEST Project [15]. This measurement assesses the amount of the moisture migrating through the open surface of a sample when the sample is exposed to cyclic changes in relative humidity. Moisture buffering capacity of a material depends on the above mentioned sorption isotherm and vapor permeability. In previous reports, the moisture buffer value (MBV) of rape straw concrete and hemp shives for hemp concrete were found to be 1.84 and 2.29 g/(m^2.%RH), respectively [16]. In another study, sprayed hemp concrete materials exhibited an excellent moisture buffer capacity (MBV = 2.15 g/(m^2.%RH)) [14]. Good and average MBVs are also found for unmodified spruce (0.95 g/(m^2.%RH)) [17], wood-based medium-density fiberboard (MDF) (1.16 g/(m^2.%RH)), cellular concrete (1.04 g/(m^2.%RH)) and gypsum plaster (0.64 g/(m^2.%RH)) [15]. Moreover, hygroscopic insulation materials based on cellulose may be modified by combining them with highly hygroscopic agents (superadsorbent polymers) in order to enhance the moisture buffering capacity of such materials in comparison with other common building material as spruce boards, gypsum, concrete and brick [6].

It should be noted that MBV value depends upon surface condition, such as for example finishing coating applied on the base material. The MBV can be determined for whole material that integrate of different material elements, e.g. for materials with a surface coating. For example, the finishing coatings for the hygroscopic materials were proposed in terms of protecting from liquid water, UV radiation and durability [18]. In [17], the spruce wooden was coated with wax particles, resulting in improving moisture buffering ability. The use carnauba wax particles/zinc oxide nanoparticles coating onto the surface of spruce wood led to additional roughness on the wood surface, making wood superhydrophobic, and enhanced the natural moisture buffering capability of spruce [18]. On the contrary, a decrease in moisture buffering effectiveness was observed by using four finishing coatings from Acrylic primer and Vinyl for commercial building materials (gypsum board, gypsum plaster, gypsum + lime plaster) [19]. In another study, the coating water-borne lacquer Kiva with low water vapor permeability and water vapor-permeable soap finish were applied on pine surfaces. The results showed that the lacquer treatment decreased by 50% the moisture buffering value when compared to the sample without treatment, but soap treatment had no effect on the moisture buffering value [20].

The hygrothermal properties of insulation materials are also evaluated by their thermal conductivity (k-value). Energy used for space heating and cooling can be decreased by using low-thermal-conductivity materials. The k-value of insulation materials depends on the material's density, porosity, moisture content and temperature. In general, a higher temperature leads to higher k-values at higher material density [21–23]. The thermal conductivity is also linked to the moisture content inside the material, higher k-values are obtained when the moisture content raises [21,24]. Consequently, the variations of k-value with moisture content of insulation materials must be investigated in order to evaluate their influence on building's energy performance.

On the other hand, in the past, the most popular board materials such as fiberboard, particleboard, medium-density fiberboard (MDF) and high-density fiberboard (HDF) used phenol–formaldehyde (PF), urea–formaldehyde (UF), urea–melamine–formalde