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Water vapour diffusion resistance of larch (*Larix decidua*) bark insulation panels and application considerations based on numeric modelling

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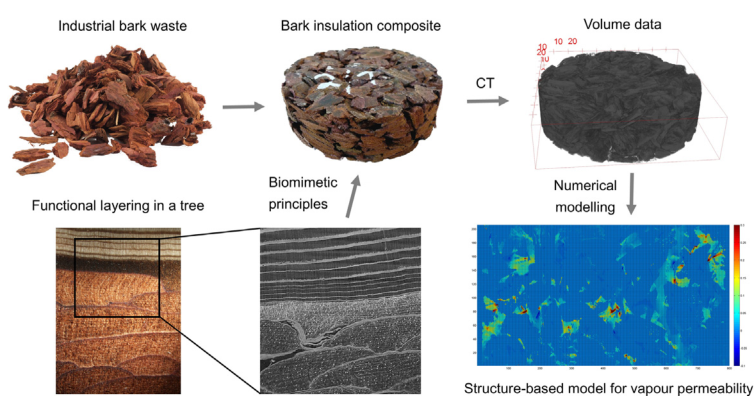
HIGHLIGHTS

- Larch bark can be used to produce bio-based thermal insulation materials.
- The vapour permeability of these composites can be influenced in production.
- Computed tomography is suitable to illuminate the bark composites' structure.
- Structure-based models can be used to predict the composites' vapour permeability.
- Miming bark's structure in a composite results in functional insulation materials.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper focuses on the vapour diffusion resistance of light particleboard produced from larch (*Larix decidua*) bark for thermal insulation applications. The influence of panel density and particle orientation, as well as particle size was evaluated in this respect. The former proved to have the most important effect. The panels' structure was illuminated by means of computed tomography and used as an input for a structure-based numeric model for vapour diffusion. The model was found to be suitable to describe the mass flow in the panels and was used to propose some optimisation of panel structure to serve for special needs in building engineering.

1. Introduction

Lately insulation materials out of larch (*Larix decidua*) bark have been developed, combining a sustainable raw material and good availability because bark is a traditional by-product in timber industry [10]. The material was found to be suitable to press insulation boards [8] as well as using it as a loose fill material [7]. The thermal conductivity of such panels has a lower limit of approximately 0.05 W/(m·K) and they have a rather high heat storage capacity (approximately 1800 J/(kg·K)), compared with other insulation materials [7,23].

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On a tree, bark prevents mechanical damage, insect and fungi attack, heat and frost damage, but also the loss of water. The bark's morphology is adapted to the special environmental conditions of a habitat [25]. Bark is a complex structure consisting of the phloem next to the cambium, from which after some time the pellogen or cork cambium separates the periderm by producing centrifugally phellem and centripetally phelloderm cells. The moisture properties of bark have been studied focusing on equilibrium moisture content [30], and regarding the bark's ability to protect a tree from moisture loss [20].

Mass transfer through wood has been extensively studied since the 1950s [18,29]. Wood and wood-based materials have a high hygroscopicity. Humidity sorption and desorption processes in wood could play an important part in the energy use of buildings, which could come up to 20% of heating energy consumption [31].

Vapour diffusion in wood is difficult to describe because of the presence of pits, cell cavities, and heterogeneous rings [14,34]. It was shown that in bamboo the vapour diffusion resistance is around 2–4 times lower in longitudinal direction than it is in radial and tangential direction due to vascular bundle vessels providing straight longitudinal conduits [4]. Moreover, water takes on different aggregate states in wood – liquid water when the material is saturated, vapour in the hygroscopic zone [2].

A study focusing on the vapour flux in various wood-based materials showed that the water vapour diffusion resistance factor (μ-value) varies insignificantly with fibreboard and particleboard, but has higher variation with OSB caused by the irregular span size. The μ-value increases exponentially with board density [28]. The vapour diffusion resistance of surface layers of wood-based panels is higher when they have a distinct density profile. For particleboards it can be 4–10 times higher than in middle layers [12]. As a consequence, the μ-value of a wood-based material is also a function of its thickness [28,31]. Vapour diffusion resistance measurements of different studies are difficult to compare due to a large number of parameters involved (vapour pressure difference, moisture content, specimen thickness, particle size, etc.). It is rather suggested to classify materials regarding their ability to allow vapour to pass [31].

The water vapour diffusion properties of bark layers (*Tsuga canadensis*) were investigated and it was found that bark retards the radial moisture flow in a living stem and prevents its desiccation. Thin-walled periderm tissue sorbs three times, thick-walled one thirty times slower than the xylem [32]. Cell wall thickness and the anatomical direction of the vapour flow is another important parameter shown on the basis of bamboo [4]. The μ-value of bio-based insulation materials (hemp, wood wool, wood fibre, straw-starch, corn pith-alginate) was studied finding that it is significantly higher with low relative air humidity (35% compared with 70%) and that differences between materials are shortened when the relative air humidity increases [21]. In general, the μ-value is about two times higher under dry conditions, compared to wet materials [28].

It was reported that the dominant moisture transfer mechanism in wood-based composites is diffusion through voids, whereas in wood it is bound-water diffusion [33]. Therefore, the structure of bark insulation panels might be a means for panels with targeted vapour diffusion properties. It could be shown for bark insulation panels that particle orientation has a significant influence on the panels' thermal conductivity [9].

Most existing insulation materials have a high vapour permeability [6]. Water vapour moves into the construction and can cause condensation in cold layers depending on the sorption ability of the material [16,15]. For this reason the vapour flow through an insulation layer has to be controlled [1], most of the time by the application of plastic foils on the inner (warm) side of an insulation layer. It was shown that the diffusion characteristics of a building envelope should be adapted to the specific climatic conditions in order to create a healthy living environment [11].

Panels made from larch bark with macroscopic structure variations shall be studied in terms of their water vapour diffusion properties in this study. It shall be evaluated to which extent it is feasible to mimic a tree, for which radial vapour flow is adjusted by the bark structure on microscopic level [32]. This would enable bio-based insulation materials with very specific vapour diffusion characteristics, favouring comfort for residents and durable constructions.

2. Methodology

2.1. Specimen preparation

The larch bark (*Larix decidua*) for the current study was collected in a small sawmill near Salzburg/Austria. Sample taking was carried out following the rules of Paper Wood Austria [22] for industrial wood chips acceptance. The bark material was dried to a moisture content (MC) of 5% in a vacuum dryer (Brunner High VAC-S/HV-S1), subsequently milled in a four-spindle shredder and fractionated using a laboratory sieving machine. Thereby two bark fractions with particles larger than 3 mm and smaller than 6 mm, and particles larger than 10 mm and smaller than 30 mm were produced.

These bark particles were mixed with a urea formaldehyde resin (Metadynea, 67% solid content, 2% – solid content hardener referred to solid content resin – ammonium sulphate as hardener) using a resin content of 10 and 20% (mass of solid resin referred to the mass of dry wood). The resin used is a standard adhesive for particleboard production which has limited stability to hydrolytic degradation but could be modified to improve these properties [13]. Finally, bark based insulation panels with a size of 240 × 350 mm^2, a thickness of 30 mm, two different particle orientations (parallel and perpendicular to the panel plane), and a target density of 200, 350, 500, and 650 kg/m^3 were produced. The orientation of particles was conducted manually with an aluminium stick in a press form which was mounted horizontally (horizontal particles) and in angle of 45° (vertical particles). The panels were cured using a laboratory press (Höfer HL OP 280, 1 × 1 m^2) with a pressing temperature of 180 °C (DOE Table 1).

After conditioning the panels at 20 °C and 65% relative air humidity (RH) until equilibrium moisture content was reached, the panels were cut into circular samples with a diameter of 100 mm, resulting in a surface of 7854 mm^2 (Fig. 1).

2.2. Water vapour diffusion resistance factor measurement

The measurement of the water vapour diffusion resistance factor (μ-value) was conducted in the style of [5]. The measuring principle is that the sample is subjected to a water vapour partial pressure difference under constant temperature. The circular samples were mounted in glass cups with a diameter of 100 mm and a height of 100 mm by closing gaps with a silicon sealant. Silica gel and desalinated water were filled until 15 mm below the lower surface of the sample. These materials cause an air humidity of 0% (dry-cup) and 100% (wet-cup) respectively within the cup. The resistance of the air layer was not taken into account for calculation. Therefore, the true diffusion resistance of the materials may be slightly lower. The cups with the samples were stored in an air-conditioned chamber (20 °C, 65% RH). Periodical weighing enabled to determine the vapour diffusion stream according to Eq. (1). Weighing was conducted until the mass change between two weighings was constant within ±5% of the mean value. The diffusion stream density was determined following Eqs. (2)-(4). Finally,