Composites Part B 106 (2016) 285–293

Contents lists available at ScienceDirect

Composites Part B

journal homepage: www.elsevier.com/locate/compositesb

Hydrophobic treatment of wood fibrous thermal insulator by octadecyltrichlorosilane and its influence on hygric properties and resistance against moulds

Anuj Kumar [a, b, *], Kamil Staněk [b], Pavla Ryparová [a], Petr Hajek [a, b], Jan Tywoniak [a, b]

[a] Czech Technical University in Prague, Faculty of Civil Engineering, Department of Building Structures, Thákurova 7, 166 29 Praha 6, Czech Republic
[b] University Centre for Energy Efficient Buildings of Technical University in Prague, Třinecká 1024, 273 43 Buštěhrad, Czech Republic

ARTICLE INFO

Article history:
Received 30 June 2016
Received in revised form
19 August 2016
Accepted 13 September 2016
Available online 16 September 2016

Keywords:
Wood fibers
Thermal insulator
Hydrophobic treatment
Hygric property
Mould

ABSTRACT

The natural fibrous materials are widely used as thermal insulator for building application. The thermal insulating performance of natural fibrous material are affecting by the high humidity and temperature. Due to high moisture in natural fibrous insulators, they are very susceptible for microorganisms attack as well as the reduction in the thermal insulating properties. In this work, hydrophobic surface treatment was given to the wood fibrous insulator using octadecyltrichlorosilane (OTS). The deposition of OTS monolayers on wood fibers surface was confirmed by X-ray photoelectron microscopy (XPS), scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR) and water contact angle of wood fibers measured by sessile drop method. The influence of hydrophobic treatment on hygric properties of wood fibrous insulator was characterized using especially designed double-climatic set-up. The effectiveness of hydrophobic treated wood fibers towards mould fungi growth was also examined. The hydrophobic treatment improved the hygric properties and effectiveness towards mould significantly.

1. Introduction

Insulation materials are extensively used to reduce the heat losses (or gains) from thermal system in buildings. In building envelope, the insulation layers both interior and exterior were used to account for most of the thermal resistance between the hot (or cold) element/s [1]. The thermal insulation materials are highly porous, and consist of a solid matrix full of small voids that comprise 90% or more of the total volume. These voids contain air or some other harmless gas such as CO_2 [2] for example polyurethane and polystyrene thermal insulator. Various factors influenced the apparent thermal conductivity of the insulator such as bulk density, type of material, water content, temperature and thickness etc., as well as the heat transfer mechanisms (i.e. gas convection, solid and gas conduction and long-wave radiation within the voids) plays vital role [2].

The various types of thermal insulating materials both traditionally or non-traditionally types are commonly used in buildings. According to Jelle et al. [3] mineral wool, expanded polystyrene, extruded polystyrene, polyurethane, vacuum insulation panels (VIP), gas insulation panels, aerogels, and future possibilities like vacuum insulation materials, nano insulation materials and dynamic insulation materials types of thermal insulators available commercially. He also discussed in details about the advantages and disadvantages of the thermal building insulation materials. The traditional materials have some level of disadvantages. For example mineral wool: They required very high amount of energy in processing; glass wool is produced from borosilicate glass at a temperature around 1400 °C and rock wool is produced from melting stone (diabase, dolerite) at about 1500 °C [3]. The fossil fuel or crude oil based thermal insulators i.e. expanded polystyrene, extruded polystyrene, polyurethane are not sustainable and environment friendly due to the drastic depletion of fossil fuels [4,5]. The vacuum insulation panels (VIP) has showing promising very low thermal conductivity in fresh condition to typically 8 mW/(mK) [6–9], but big disadvantages such as puncturing the VIP envelope, which might be caused by nails and similar, causes an increase in the thermal conductivity to about 20 mW/(mK) and VIP cannot be

* Corresponding author. Czech Technical University in Prague, Faculty of Civil Engineering, Department of Building Structures, Thákurova 7, 166 29 Praha 6, Czech Republic.
E-mail addresses: anuj.kumar@fsv.cvut.cz, anuj.saroha@gmail.com (A. Kumar).

http://dx.doi.org/10.1016/j.compositesb.2016.09.034
1359-8368/

cut for adjustment at building site as well cost-effectiveness still very high compare to traditional materials [3,9]. Aerogels are the best performing thermal insulating material due to very low thermal conductivities 4 mW/(mK) [10,11], but it very far from the real application in building envelope due to very expensive production cost.

In recent years, the development of thermal insulators using renewable raw materials of natural origin are brings the interest of researchers and industries. According to Pacheco-Torgal [12], the European Union (EU) also targeted to develop the eco-efficient building materials in the frame of H2020 program with an ultimate goal as follows.

> “By 2020 the renovation and construction of buildings and infrastructure will be made to high resource efficiency levels. The Lifecycle approach will be widely applied; all new buildings will be nearly zero-energy and highly material efficient and policies for renovating the existing building stock will be in place so that it is cost-efficiently refurbished at a rate of 2% per year. 70% of nonhazardous construction and demolition waste will be recycled”.

Among the natural origin renewable raw materials the use of fibrous materials such as kenaf [13–15], sheep wool [16,17], hemp [18,19], and flax [18,19] were increased in last few years. Wood fibers are one of the most important basic materials for the production of composite wood products. Fiberboards include hardboards, medium density fiberboards (MDF) [20–22] and low-density boards [23]. The latter are used as insulation, cladding, and roofing material for buildings as well as for sound absorption and similar applications. Any fiberboard can be classified according to particle size, production method, and density. The characteristic density for low-density boards is in the range of 100–400 kg/m^3 [24]. Some commercially available wood-fiber insulators have lower density approx. 50 kg/m^3 and also low thermal conductivity 0.038 [W/(m*K)] and high specific heat capacity 2100 [J/(kg*K)] [24].

The natural insulating (low density natural fibers insulators board) as discussed above having comparable physical properties (i.e. thermal conductivity, density) with the commonly used fossil fuel based insulators; however they show even high moisture sensitivity that directly influence the thermal insulation properties [25–27]. In addition to this mould growth on the surface of fibrous insulating panels and in between the space and outer wall as result of high humidity level also a big issue [28–31]. The plant based fibers or natural origin fibers mainly composed of cellulose, hemicellulose and lignin polymers. These polymers mainly have free hydroxyl group (-OH), which make them reactive towards the humidity and moisture [32,33]. Various surface treatments of wood or wood fibers can control the moisture buffering properties such as natural hydrophobic coatings [34,35] and nanocoatings [36,37].

Similar, hydrophobic surface treatment can be a feasible solution to control the hygric properties of wood fibrous insulators in high humidity conditions. The main aim of present work focuses on the hydrophobic surface treatment of wood fibrous insulator using octadecyltrichlorosilane (OTS) and characterization of surface modified fibers. The surface modified wood fiber was evaluated by FTIR, XPS, SEM-EDX and water contact angle was measured by sessile drop method. Further, the effectiveness of hydrophobic properties wood fibers was evaluated by water condensation and molts growth experiments.

2. Experimental

In this work we have used the natural wood-fibrous insulators (BFI) supplied by Stecio (Germany). The wood-fibrous insulator having thermal conductivity [0.038 W/(m*K)], high specific heat capacity 2100 [J/(kg*K)] and density [160 kg/m^3]. The Octadecyltrichlorosilane (OTS) and *n*-hexane were procured from Sigma Aldrich (CR).

2.1. Methodology

2.1.1. Hydrophobization of wood-fibrous insulator

The OTS and *n*-hexane solution was prepared in 1/100 (V/V) ratio. The WFI samples (300 × 300 × 40 mm^3) were dipped into the OTS/n-hexane solution for 30 min. After the treatment the samples were washed with pure *n*-hexane to remove the un-reacted OTS molecules and tried the samples at 60 °C for 2 h.

2.1.2. Interstitial condensation experiment in climatic double-chamber

An experiment to investigate the behavior of fibrous thermal insulators under interstitial condensation conditions was carried out using climatic double-chamber setup (warm-side chamber – test frame with samples – cold-side chamber), as shown in Fig. 1. Three material samples were tested: original untreated wood-fibers (Control WF), OTS treated wood-fibers (Treated WF), and hydrophobic mineral wool (Mineral Wool). Their basic material properties are summarized in Table 1. All the samples had a thickness of 40 mm.

The main aim of this experiment was how the hydrophobic treatment of wood-fiber insulator influences its behavior during interstitial condensation compared to original (untreated) sample,

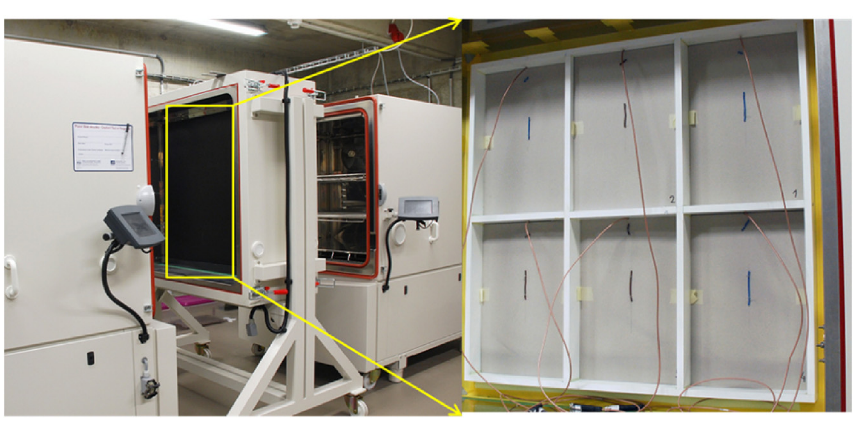

Fig. 1. Double-climatic chamber setup used in condensation experiment.