Construction and Building Materials 184 (2018) 330–343

Contents lists available at ScienceDirect

Construction and Building Materials

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

Design and properties of a new sustainable construction material based on date palm fibers and lime

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HIGHLIGHTS

- We used date palm fiber and lime in production of new eco-friendly insulation material.
- Using experimental investigations, several compositions are studied.
- Very good thermo-acoustic properties.
- The transpirability and hygroscopicity of the new material makes it an excellent regulator for indoor humidity level.
- The produced material is low cost and based on agricultural waste.

ARTICLE INFO

Article history:
Received 19 January 2017
Received in revised form 10 October 2017
Accepted 23 June 2018

Keywords:
Date palm fiber
Thermal properties
Mechanical testing
Acoustic absorption
Hygric regulator

ABSTRACT

Every year, huge quantities of date palm fibers (DPF) are produced and wasted all over the world. Using this natural fiber as raw material would contribute to the valorization of natural sustainable resources. This paper presents an experimental investigation of a new eco-material based on date palm fiber and lime. The experiments on the elaborated material investigate some mechanical, thermal, acoustic properties and moisture buffering capacity. The influence of the fiber/lime ratio on the behavior of the lightweight aggregate was studied systematically. The results of compressive strength testing indicated that PDF incorporation led to a reduction in resistance limit, however, the recorded average values are still acceptable. Also, it was observed that the thermal conductivity is sensitive to the variation of the fiber/lime composition ratio. The measured thermal conductivity reached a minimum of 0.091 W/m.K for samples of 50% fiber, which indicates that it can be used as a good thermal insulator. With regard to the sound absorption, the new material reveals good absorption capacity based on the measured sound absorption coefficient which is for 50% of fiber: for medium and high frequencies 0.65 and 0.55 respectively. Due to its porous morphology, the proposed material has the ability to absorb water vapor in a high relative humidity environment and to restore it in a dry one. Hence, it could therefore act as a hygric regulator. Measurements of moisture buffer value revealed that the material is classified as good or excellent depending on the percentage of fiber.

1. Introduction

Nowadays, our society is facing major problems of energy and environmental aspects. Rationalizing our energy consumption and promoting the use of materials with low environmental impact are measures to be taken to slow the degradation of our environment as well as early exhaustion of available energy resources.

The building sector has over 40% of global energy consumption and 56.7% in carbon dioxide emissions, which is considerable [1]. Therefore, the use of reliable insulation materials and the integration of passive air conditioning systems are two measures to be taken among others in order to mutate to a more rational energy model. From an environmental point of view, it is very advantageous to use natural fibers as an alternative to synthetic and mineral ones. The construction industry should gradually adopt new methods and new vegetable fiber materials. This will contribute to reducing the use of energy in its primary form as well as CO_2 emissions.

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https://doi.org/10.1016/j.conbuildmat.2018.06.196
0950-0618/

Exploring new eco-friendly materials and selecting their desired distinctive characteristics and attributes would lead not only to innovation in design but also to expand new sustainable design [2]. The need to develop new effective materials for thermal and acoustic insulation with a very low environmental impact has prompted researchers to invest in this area. Vegetable fibers are cheap, available in most parts of the world and their cost is minimal contribution to the total cost of the composite. Compared to steel fibers, because of their flexibility the plant fibers are easy to handle especially when a large percentage of fiber is used [3]. Composites based on vegetable fibers have advantageous properties in terms of thermal and acoustic insulation and an ability to regulate the humidity inside buildings by absorption and / or desorption of water vapor depending on the relative humidity of the air [4].

The date palm (phonex dactylifera) is one of the most cultivated palms around the word [5]. It was also one of the first domesticated trees. The date palm supplies a large proportion of the necessities of life in desert areas. According to a poem of ancient Persia and Babylonia, There were 360 uses of the date palm [6].

The abundance of date palm fiber in North Africa and Middle East presents an opportunity to develop green building materials at low cost. There are 18.7 million palm trees scattered over around 100,000 farms in Algeria country wide in 2009. Approximately 210,000 tons of date palm petioles, 73,000 tons of leaves and 52,000 tons of brunches are produced only in Algeria [7]. The annual world production of date palm fiber is estimated to 1.13 million tons [8].

The first studies on the date palm fibers began to emerge one decade ago. In the field of composite materials, mechanical properties of date palm fiber reinforced composites was investigated by Al-Sulaiman [8]. Abu-Sharkh and Hamid [9] were interested in the behavior of date palm leaves compounded with polypropylene and UV stabilizers. It has been found that the composite is much more stable than polypropylene under both the severe natural weathering conditions of Saudi Arabia and in accelerated weathering trials. By their research Kriker et al. [10] have investigated the properties of date palm fibers and the concrete reinforced with these fibers in hot and dry climate. Both the durability of date palm fibers immersed in alkaline solutions and the effect of curing (in wet and hot dry environments) on concrete have also been examined [11].

Recently, more and more researchers have become interested in date palm as natural fiber source with good mechanical properties and giving the opportunity to the development of new efficient materials with what normally considered waste or used in low value products. In this sense Noorunnisa Khanam and AlMaadeed [12] investigate the properties of date palm fiber reinforcing recycled polymer blend composites. Likewise the mechanical properties of composites based on recycled liner low-density polyethylene blended with date palm wood is studied by AlMaadeed et al. [13]. The potential of using date palm fibers as reinforcement of polymeric composites is discussed by Alsaeed et al. [14].

In scientific literature, we find that most researches on date palm fiber have investigated the potential effect that could have the use of this fiber on the mechanical properties of composites [15–17]. However, some unconventional ideas have emerged. For example, Riahi et al. [18] proposed the use of date palm fibers filters as porous medium for tertiary domestic wastewater treatment.

The date palm will grow in any tropical or subtropical climate but for fruit maturation, it is necessary to have a long hot growing season and a nearly rainless period when the fruit is ripening. To resist temperatures that exceed 50° C in the shade, the date palm certainly has a good thermal insulation which keeps its trunk to adequate and suitable temperatures for its development. Indeed, Agoudjil et al. [7] experimentally investigated the thermophysical, chemical and dielectric characteristics of three varieties of date palm wood. Based on the measured thermal conductivity, they concluded that the date palm wood is a very good candidate for a safe development of an insulating material compared to other natural ones. It is noted that the conductivity of date palm fibers is less than that of hemp and still close to sisal. This fact makes date palm fibers suitable for insulation purposes.

For building thermal insulation Benmansour et al. [19] proposed a new material composed of natural cement, sand and date palm fiber. The results of their experimental investigation reveal that the incorporation of DPF (date palm fibers) reduces the thermal conductivity and the compressive strength of the composite. They concluded that using a suitable DPF percentage in the mortar allows obtaining a composite with good thermal and mechanical properties which can be used in buildings for the enhancement of thermal insulation. Chikhi, et al. [20,21] have developed a gypsum based material containing DPF. The thermophysical behavior investigation shows that the increasing of DPF concentration in gypsum matrix decreases the thermal conductivity and the composites density.

All materials react dynamically to moisture of the ambient air. Some of them can bring added value in regulating the temperature and humidity of local due to their hygrothermal capacity. One way of controlling indoor relative humidity amplitudes without adding energy costs to the building is to use the porous materials ability to release moisture from/to the adjacent environment [22]. Experimental investigation of sprayed hemp concrete shows that this eco-material has an excellent moisture buffer capacity [23]. Cerolini et al. [24] concluded that cellulose-based material seems to be the most suitable for moisture buffer application. The content in cellulose of date palm fiber reached 46% which is greater than that of coir and less than hemp and sisal [25]. Unfortunately, we did not find works on the ability of date palm fiber based materials to react with air moisture.

From an acoustic point of view, it is highly desirable that the insulating material also have a good ability to absorb sound waves. Many researches have been conducted in developing sound absorption panels made of natural fibers. Le et al. [26] in their study find that starch-hemp composite materials are good sound absorber material for medium and high frequencies with a value around 0.7. Elwaleed et al. [5] tested the sound absorption properties of a single layer of date palm fiber. A perforated plat was used to enhance the sound absorption of the fiber layer. The results showed that when facing the date palm fiber sample with perforated plate the sound absorption coefficient improved at higher and lower frequency ranges. This increase in sound absorption coincided with reduction in medium frequency absorption.

In this research, we performed experiments on a construction material based on date palm fibers given the need of new materials and techniques for development of renewable resources on the basis of green and clean processes. The idea is to conceive an ecological insulation material at very low cost and which can meet the technical requirements in the building sector. In this work, we focus on characterization of mechanical, thermal and acoustic absorption properties of a new insulation material made from date palm fiber. The study also deals with dynamic characterization of moisture buffer value (MBV) held according to the NORDTEST protocol. The new material concerned by this study is an aggregate of date palm fiber and lime. According to the results of experimental investigations, the material has very good properties in terms of thermal insulation, excellent moisture buffering capacity and also good sound absorption capacity.