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Experimental thermal characterization of bio-based materials (Aleppo Pine wood, cork and their composites) for building insulation

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ABSTRACT

This paper presents an experimental study of the thermal conductivity, thermal resistance, specific heat and thermal diffusivity of wood, cork and their composites. The first part is devoted to the determination of the thermal resistance of composite materials elaborated from solid Aleppo Pine wood, laminated timber wood and black agglomerated cork. From experimental results, we can predict the values of the thermal conductivity, specific heat using a modulated differential scanning calorimetry (MDSC) of different samples. For the thermal conductivity, we use two different methods: the flow meter and a thermal conductivity meter (TC meter) at laboratory conditions (23 °C, 50% RH). However, we have the possibility to calculate the thermal resistance and the thermal diffusivity and make comparison between the two methods. The results have been compared with other experimental researches and usual building materials. Furthermore, the aim of this study is to show the influence of the moisture on the values of the thermal properties of wood and cork which has been performed in a climatic chamber (23 °C, 80% RH). The results indicate that increasing the mass of the samples leads to an increase of the value of the thermal conductivity and a decrease in thermal resistance of sandwich structures.

1. Introduction

Nowadays, the energy consumption is increasing continuously in all fields worldwide. At the same time, the cost of energy increased because of depletion of energy sources [1] and heavy environmental impact (ozone layer depletion, global warming, climate change, etc.) [2]. Therefore, in order to reduce energy consumption, particularly, in building we have elaborated a new composite material based on wood and cork. The green solution is the use of bio based materials Aleppo Pine wood (*Pinus halepensis*) and black agglomerated of cork as alternative material in the development of composite materials.

Experimental determination of thermal parameters of these composite materials for construction is primordial in our days. It helps manufacturers to make a distinct choice after a better knowing of their work materials.

Three principal properties are usually used to describe the heat transport through a material. These are the thermal conductivity, specific heat and thermal diffusivity. The thermal conductivity is the parameter, which describes the material's ability to transmit heat [3]. It is one of the basic parameters used to determine properties such as the thermal resistance (R) or alternatively the overall heat transfer coefficient (U) [4]. It is measured using two methods: the flow meter and the TC meter at a laboratory conditions (23 °C, 50%). The obtained results show that both the two methods are efficient but the flow meter method gives more precision for the black agglomerated cork. For this reason, all the following results are obtained from measurements using the flow meter. Samples of whole solid, laminated timber wood and black agglomerated cork are conditioned in a climatic chamber in which the relative humidity is 80% and the temperature is fixed at 23 °C. The results show the sensitivity of this bio based materials and their sandwich assemblies to the water content; its thermal properties must be taken into account when we build with it.

Specific heat describes the capacity of the material to absorb, store and release heat. It is widely used in thermodynamic analysis

Abbreviations: APLTW, Aleppo Pine laminated timber wood; APSW, Aleppo Pine solid wood; BAC, black agglomerated of cork; CSTB, Scientific and Technical Building Center; HFM, heat flow meter; MDSC, modulated differential scanning calorimetry; PSW, polywood-faced sandwich; TC meter, thermal conductivity meter.

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Fig. 1. Photos of black agglomerated cork tested specimens.

and in dynamic simulation modeling of buildings [4]. In this work, we measure the specific heat capacity of the three different materials using a calorimeter apparatus. The obtained results are in the temperature range of 0–50 °C, the aim of this part is to determinate the specific heat of inhomogeneous materials using a differential scanning calorimetry [5].

Thermal diffusivity is the rate of heat diffusion per unit time [6], it is the thermophysical property that defines the speed of heat propagation by conduction during changes of temperature; It is the key parameter that controls the temperature distribution as a function of time [7].

There are a lot of papers that assessed the thermal properties of wood, which are needed in applications such as fuel conversion, building construction and other fields of industry [8]. Harada et al. [9] measured the thermal conductivity, specific heat and thermal diffusivity of 13 species of wood by means of the laser flash method to investigate the thermal properties of wood during the heating process. Suleiman et al. [10] studied thermal conductivity and diffusivity of Swedish wood. The results showed that thermal conductivity slightly increases with temperature increase (20–100 °C) in both longitudinal and transverse directions, and detect a significant difference in the thermal conductivity between the longitudinal and the transverse directions.

The cork is a good insulator, it is assessed in the work of Silva et al. [11] in which they showed the chemical, physical and mechanical properties and its applications. Chekri et al. [12] discussed the thermal conductivity, thermal diffusivity and heat capacity of the composite material granular. The thermal conductivity is obtained by using an alternative hot plate method in steady state regime. The results show that this composite material granular can be considered as being homogeneous for particles in the granular class $D = 6.3–8$ mm and for granular cork volume proportion content greater than 40%. Olivares et al. [13] and Chekri et al. [14] examined the feasibility of using composites based on cork–gypsum. The results of Olivares et al. showed the potential of these composite (cork-gypsum) to be used as a partition wall owing to their thermal insulating obtained from the cork. In addition to that, the results of Chekri et al. have shown the efficiency of method of asymmetrical transient hot Plate method for thermal characterization of high insulating granular material. Thermal conductivity is also obtained by using an alternative hot plate method in steady state regime.

For the sandwich assemblies wood-cork, there were a few works in the field of sandwich structures. We notice Kawasaki and Kawai [15] which make a large studies of thermal insulation and warmth-keeping properties of thick plywood-faced sandwich panels with low density fiberboard (plywood-faced sandwich, PSW). As in our studies, the λ values were measured for PSW panels, their core and face elements using a flow meter apparatus. In this paper, we compared our results with those obtained by Kawasaki and Kawai.

2. Materials and methods

2.1. Used materials

2.1.1. Black agglomerated cork (BAC)

Three cork specimens are tested by means of the TC meter apparatus have a square form of 0.04 m of thickness and 0.1 m of length (Fig. 1). Three other tested cork specimens are tested by means of the flow meter have also a square form with 0.04 m of thicknesses and 0.2 m of length (Fig. 1). The agglomerated cork is a material derived from the bark cork oak tree (*Quercus Suber*) [16]. It is collected usually at the edge of the Mediterranean: Portugal, Spain, Algeria, Morocco, Tunisia and France [17]. It is obtained from cork granules after grinding tablets in an autoclave at 350 °C. The resin content of the bark plays the role of a natural bind to agglomerate the granules, when the panels come out of the autoclave, they will be traversed by a flow of water for cooling.

2.1.2. Aleppo Pine wood (APW)

Six specimens of solid wood and laminated timber wood are tested by means of the TC meter have a square form with 0.02 m of thicknesses and 0.1 m of length (Fig. 2). Six other specimens are tested by means of the flow meter have a square form with 0.02 m of thicknesses and 0.2 m of length (Fig. 2). The Aleppo Pine (*Pinus halepensis*) is a conifer that belongs to the Panacea family. It is a rustic species, which characterizes the semiarid Mediterranean bioclimatic zone [18]. The wood of Aleppo Pine is a light species; its low

Fig. 2. Photos of Aleppo Pine wood tested specimens.