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Moisture content influence on the thermal conductivity and diffusivity of wood–concrete composite

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HIGHLIGHTS

- The influence of moisture content on the thermal proprieties of wood–concrete is studied.
- Lightening the concrete by wood shavings increases its thermal insulation capacity.
- Thermal conductivity increases rapidly with water content.
- Thermal diffusivity presents a maximum corresponding to a water content value W_m.
- The values of thermal diffusivity depend on the used counting model.

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ABSTRACT

The aim of the work reported in this paper is to determine the influence of moisture content on the thermal proprieties of wood–concrete composite, i.e. thermal conductivity and thermal diffusivity. The wood shavings have been incorporated, without any preliminary treatment, into a sand–cement mixture. Five formulations containing different percentage of shavings have been prepared and have been examined herein. The experimental results show that the lightening of concrete by wood shavings increases the thermal insulation capacity by decreasing the thermal conductivity and diffusivity; however these proprieties are strongly dependent on water content. The thermal conductivity increases rapidly with water content. Its experimental evolution with water content was confirmed by the comparison with three theoretical models. The values of the thermal diffusivity depend on the used counting model. The results stemming from three most used models are compared between them, and they show that in general the thermal diffusivity presents a maximum corresponding to a water content value W_m.

1. Introduction

The composite wood–concrete has been studied a lot these last years because wood fibers have many advantages: low cost, healthier production processes for the production of composites with different forms, the renewal and the recycling [1]. In addition, wood fibers are naturally degradable [2], which is not negligible in the current context of waste limitation. The reinforcement of concrete by wood fibers gives a composite material which can be used in many applications such as floor formwork, suspended ceilings, screeds and interior masonry blocks .

Several studies have focused on the use of wood as ash in concrete [3–5]. Based on its physical, chemical, and microstructural properties, the authors reported that wood ash has a significant potential for use in low and medium strength concrete, masonry products, roller-compacted concrete pavements (RCCPs), materials for road base, and blended cements. Coatanlem et al. [6] study the durability of wood chipping concrete mixture by examining compressive strength, flexural strength and microstructure. The results are encouraging and indicate the feasibility of producing a lightweight concrete. Bederina and Quéneudec [7], Ziregue [8] show that the addition of wood shavings in concrete improves its thermal insulation performance, while decreasing its compressive strength. However, it is possible to ensure a compromise between the compressive strength and the thermal conductivity for obtaining a structural insulation concrete.

Nevertheless, this material can present a high hygroscopic behavior due to the strong absorption of wood particles. When this material has being exposed to the conditions of temperature (T) and relative humidity (RH), which are variable between the interior

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and the exterior of the building, heat and moisture transfers occur within the medium. An important interaction develops between the heat and the moisture transfers and the different transport properties [9]. Indeed, the thermal, phonic and mechanical properties of the material are modified. It is thus crucial to quantify the variation of these properties with temperature and moisture content of the sample. But, this is not considered in most studies treating the use of this type of material in building. In this context, this study has been conducted to measure the effect of moisture content on the thermal conductivity and diffusivity of the wood–concrete composite.

2. Materials

2.1. Basic materials

The wood shavings used are a sawmill waste (Fig. 1). They correspond to the species generally used in the carpentry work in Morocco [10]. The granulometric analysis by sieving, established by a method identical to that proposed by the French standard NF P18-560 [11], demonstrates that the used wood shavings have a particle size between 8 mm and 20 mm. The sand is sea one of granulometry 0/5 and of bulk density on the order of 1500 kg/m^3. This sand is used without any washing procedure. Indeed, the test of sand equivalent made according to the standard NF EN 933-8 [12] gives the value 81%, which shows that it is a clean sand with a low percentage of clay fines, suiting perfectly for high quality concretes [13]. The cement used is Portland cement CPJ 35 equivalent to CEM II 22.5 and whose technical characteristics are in accordance with the Moroccan standard NM 10.01.004 [14]. The used mixing water is a tap water.

The concretes prepared are based on a mass ratio of 2/3 of sand and 1/3 of cement. The specimens are made with a mass ratio of water to cement (W/C) of 0.6. The study was conducted on five formulations containing different proportions of wood shavings.

2.2. Implementation of fresh concrete

The constituents are mixed in a mixer at slow speed on the order of 50 r min^{-1}, in order to obtain a good homogenization of the components. The durations of the different phases of mixing must be sufficiently long to allow a good homogenization and short enough to avoid leaving too much water to evaporate in ambient air. Thus, three phases are distinguished:

- Mixing cement and sand: 3 min.
- Adding pre-wetted wood shavings: 3 min.
- Adding mixing water and mixing: 5 min.

Fig. 1. General aspect of the used wood shavings.

Table 1
Principal physico-mechanical properties of samples.

Sample	Mix0	Mix1	Mix2	Mix3	Mix4
Mass ratio of wood shavings to cement (%)	0	6	15	24	30
Dry density (kg/m^3)	2142	1914	1779	1547	1495
Porosity (%)	21	24	31	44	55
Compressive strengths (MPa)[a]	27	16	13	9	7
Volumetric water content at the saturation W_{sat} (%)	20	22	29	42	53

[a] Compressive strength measured according to the European standard EN 196-1 [15].

2.3. Preparation of specimens

The homogenized mixture is then introduced into parallelepiped molds; two dimensions of molds were made according to the type of tests to be realized. As regards the thermal aspects, the molds of dimension (27 × 27 × 2 cm^3) were used. For mechanical strength, the molds (16 × 4 × 4 cm^3) were used. These different sizes are related to measuring devices (thermal box, mechanical press) whose dimensions are imposed. The use of the same manufacturing process, regardless of the mold, allows to work on the same material.

The specimens are preserved before and after turning out into the room test at a controlled temperature and humidity (T_a = 20 °C, RH = 60%). These conditions correspond to a standard climate and allow to reproduce real conditions of the use of the material.

2.4. Formulations

The elaborate formulations, containing various rations in wood shavings, are presented with their physico-mechanical properties in Table 1.

The density and the porosity are strongly influenced by the addition of wood shavings. Thus, a progressive decrease in density and an increase in porosity are observed. Indeed, the sand concrete, due to its small granularity, is lighter than ordinary concrete. The introduction of wood shavings reduces it more. The higher the proportion of wood shavings used the lighter the sand concrete will be [7,16,17]. This lightness is due, on the one hand, to the porous structure of wood, on the other hand, to an additional porosity led in the matrix when the water absorbed by the wood shavings evaporates during the drying.

The increase in shavings content reduces the mechanical strength of concrete. This decrease is due, on the one hand, to the low mechanical strength of the inclusions, and on the other hand, to the increase of porosity.

The water absorption capacity is very sensitive to the addition of wood shavings. Thus, there is a significant increase in W_{sat}. Indeed, wood particles have a very marked fibrous aspect. The canals which lead the sap give this material a high porosity communicating via orifices. This leads to a strong hygroscopic character [18]. It is noted that the concrete sand, itself, is characterized by an absorption capacity higher than that of ordinary concrete [19], and that the addition of wood increases it further. Similar results were obtained for hemp-concrete [20].

3. Thermal conductivity models

Many models have been proposed in the literature to predict the effective thermal conductivity of three-phase mixtures. The models used in this work are as follows:

3.1. Krischer and Kroll model [21]

The Krischer and Kroll model is a combination between the serial and the parallel models. The authors suppose that the volume fraction θ of layers oriented perpendicular to the direction of heat flow is arranged in series with the complementary fraction $(1-\theta)$ of layers oriented parallel to the direction of heat flow. Firstly, the authors suppose that the fluid phase consists only of gas (air in general). Afterwards, they extend their model for a fluid phase consisting of gas and liquid (water in general). The apparent thermal conductivity is given by a harmonic mean of the series and parallel models:

$$\lambda = \frac{1}{\frac{1-\theta}{\lambda_{//}} + \frac{\theta}{\lambda_{\perp}}} \quad (1)$$