Mater Renew Sustain Energy (2017) 6:15
DOI 10.1007/s40243-017-0099-z

ORIGINAL PAPER

Thermo-mechanical characterization of construction material lightened by olive pomace

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Received: 24 November 2016 / Accepted: 26 July 2017 / Published online: 3 August 2017

Abstract The development of porous materials requires a thorough knowledge of their physical properties. When used as thermal insulation, the properties that govern their insulating capacity are thermal conductivity, thermal diffusivity and specific heat. The presence of moisture, some of its origin, in buildings causes damage to walls that extend from the formation of mold in complete impregnation through the degradation of the thermal and mechanical performance. The major objective of this study is to determine the physical properties of a building material lightened by vegetable fiber (concrete pomace olive), used as an insulation bearer. Our goal is to develop and expand the field of use of these materials in construction. A judicious choice of additions proportions and implementation techniques will be considered. A particular interest is the thermal characteristics and mechanical strength, which is a decisive criterion for selecting a material in the construction. We determine the thermal conductivity of the materials studied with experimental equipment that allows us to make measurements of the thermal properties under actual use conditions (temperature and humidity) and also the study of the mechanical compressive strength of the materials studied and the interest in these materials is highlighted.

Keywords Porous materials · Lightened concrete · Thermo-mechanical properties · Moisture

Introduction

In the concern of reducing energy consumption which is increasing rapidly in recent years in the construction sector, the researchers are investigating the problem of optimizing the rational use of energy, specifically in construction, posing the problem of optimal thermal insulation of buildings which bring our interest [1–3]. The principle of the construction based till now on the juxtaposition of different materials each having a devoted task.

However, this accumulation of different materials is less attractive because they become expensive and eventually occupy a significant volume [4]. This explains the evolution of construction techniques and development of new materials for thermal insulation and can reduce the cost of construction, on the one hand and lower energy bills, on the other. Among these materials, lightened concrete, which are able to act as insulators while maintaining adequate levels of performance.

The use of vegetable aggregates in the concrete is part of a sustainable development approach. It has the advantage of using a renewable resource, unlike aggregates quarries whose resources are depleting. However, the lightened concretes are porous materials, and thus very sensitive to water, they are able to fix and store the moisture. This latest, addition to the issues of sustainability which it is liable to create, can in particular significantly alter the thermal performance by changing the thermo-physical properties of materials used in construction. Therefore, improving the thermal insulation of a home requires a good knowledge of the hygro-thermal behavior of walls.

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Materials

After a deep investigation on the various existing local materials in Algeria and taking into account the availability and cost, our choice was fixed on natural fibers for addition to concrete material sensible proportions and will be determined in a phase later will develop new materials that can be carriers insulates-competitive price. It is understood that the thermo-physical and mechanical characteristics of these local materials should be undertaken to confirm these choices. Selected natural fibers and on which our study will focus are: the olive pomace.

Experimental investigation of thermal conductivity and compressive strength

Several methods allow a thermo-physical characterization of this material. Among these methods, we cite the method of the hot disk (HD), the flash method and the flash laser system for measuring thermo-physical properties. The method we opted is the boxes method [5, 6], it allows to determine simultaneously the two main features namely conductivity and thermal diffusivity.

Experimental device

The device used in the laboratory is a measurement cell designed for the simultaneous determination of thermal conductivity and diffusivity of the material in steady-state. This is the EI700 device which contains:

- An enclosure A of internal dimensions (200 × 100 × 45) cm^3 used as the cold atmosphere, it is maintained at a low temperature (until −10 °C) using a heat exchanger G situated on its base. This enclosure is insulated from the external atmosphere by extruded polystyrene Fig. 1.
- Two boxes, one for the conductivity and the other to the diffusivity. These boxes are plywood, isolated from the inside by a styrodur which limit heat loss by the surfaces of boxes in contact with the outside; each box contains a heating film and act as a warm atmosphere Fig. 2.

By cooling A and heating box B, a temperature gradient is created between the two atmospheres; so that the convective exchanges on both sides of the sample are negligible. To minimize the heat exchange between the box B and the outside environment, a suitable heating voltage must be applied in such a way that the temperature inside B: Tb is as close as possible to the temperature of the room of experimentation: Ta, while remaining superior to this one ($\Delta t < 1$).

The test sample is placed between the two environments. The Samples sizes are (27 × 27 × e) cm^3, the thickness e varies from 2 to 6 cm.

Thermal conductivity

The measuring principle is based on achieving a permanent unidirectional heat flow through the sample, supposed to be homogeneous and without internal generation of heat.

Once the permanent regime is established, the thermal conductivity is given by the Fourier's:

$$\lambda = e/S\Delta T\,(V^2/R - c\Delta T),$$

λ is the thermal conductivity, in W C^{-1} m^{-1}; e is the thickness of the sample, m; S is the surface of the sample, m^2; ΔT is the difference in temperature between hot and cold faces of the sample, °C; $\Delta T'$ is the difference in temperature between the inside and the outside of the box, °C; C is the heat loss coefficient, W $°C^{-1}$; V is the tension at the heating resistance terminals, V; R is the electrical resistance, Ω.

Compressive strength

The compressive strength of concrete is measured according to the European standards NF EN 12390-4, using Seidner automatic press with a rate loading of 3 ± 0.5 kN/s.

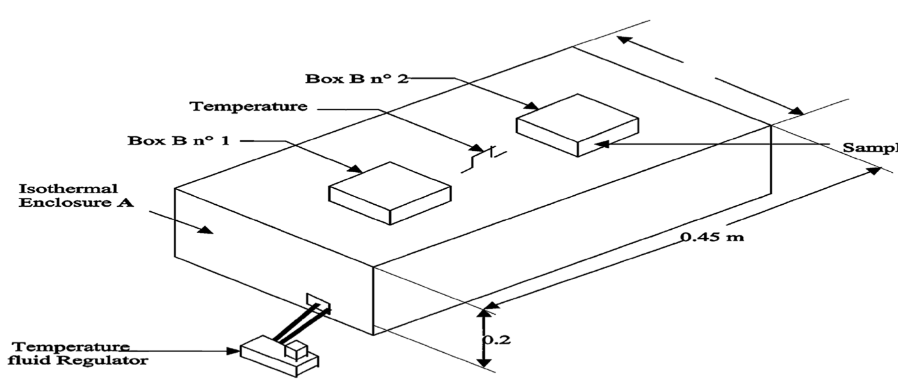

Fig. 1 Experimental setup of the boxes method

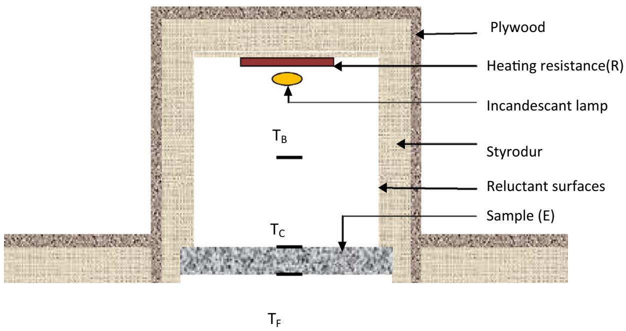

Fig. 2 Thermal conductivity and diffusivity measuring box and tube positions

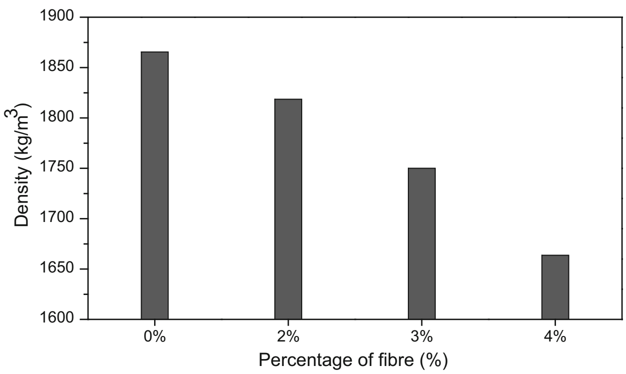

Fig. 3 Density variation with percentage of fiber for the various samples

Preparation of samples

The composition method of conventional concrete used is that of Baron-Lesage and Gorisse [7, 8] for a *W/C* ratio (water to cement) given minimum these methods seek to optimize the *S/G* (sand gravel) for better workability.

To improve the thermal properties of the concrete was incorporated fibers (olive pomace) to concrete at rates ranging from 0 to 3% (0, 1, 2, 3%) (Table 1). The specimen thickness is 6 cm. The aggregates used in the different mixtures were made from two size fractions 5/8 and 8/15, Career sand and Portland cement CPJ45 Hamma Bouziane (Constantine, East Algeria). Water is the main factor agents capable of degrading material, We carried out a study on the influence of moisture on the thermo-physical properties of the material we have prepared several samples with different volume percentages of olive pomace integrated in concrete.

Results and discussion

The measurements of dry densities were carried out after drying of the material in an oven regulated at 60 °C until their weight remains constant after 24 h (dry state).

The evolution of the dry density with the fraction of lightening in olive pomace, is illustrated in Fig. 3. It is observed that the density decreases considerably by increasing the percentage of the fibers added [9, 10], the use of the olive–pomace fibers gives a first advantage to the composite: that of lightening it. This is due to the substitution of a part of the matrix by its less dense material equivalent.

The analysis shown in Fig. 4 makes it possible to observe an increase in thermal conductivity with increasing water content. In the dry state, the thermal conductivity depends only on those of the solid matrix and the air (about 0.26 W/m k at 20 °C), this latter is much lower than the thermal conductivity of the water (about 0.60 W/m k at 20 °C), which will gradually replace the air contained in the pores, during the humidification. There is an increase in the apparent thermal conductivity of the material [11].This latter will be all the more important as the water content is high. The precision of measures on thermal conductivity is $\Delta\lambda/_{\lambda} = 6\%$. This result was observed on other materials such as sawdust concrete [12, 13, 14].

The evolution of the thermal conductivity of the lightened concrete in the dry and saturated state as a function of the olive–pomace dosage is shown in Fig. 4. We note that the conductivity evolves in the opposite direction to the fiber dosage, whether in the dry or saturated state, this is justified by the fact that the thermal conductivity of the plant fibers is infinitely small compared to the thermal conductivity of the aggregates and cement, Olive pomace

Table 1 Mix design proportion

Materials	Mix1 (0%)	Mix2 (1%)	Mix3 (2%)	Mix4 (3%)
Cement (kg/m^3)	400	400	400	400
Aggregates (kg/m^3)	1000	982	973	960
Sand (kg/m^3)	750	750	750	750
Water (kg/m^3)	240	270	290	305
Vegetable fibers (kg/m^3)	0	18	27	40

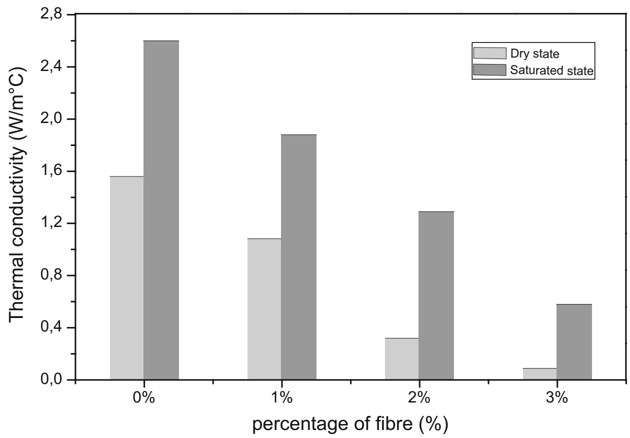

Fig. 4 Thermal conductivity of lightened concrete as function of density at dry state and saturated state

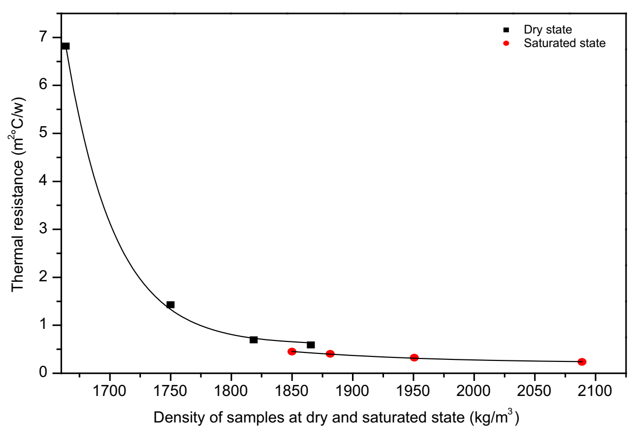

Fig. 5 Thermal resistance of lightened concrete as function of density at dry and saturated state

are insulating materials. Thus, for a given volume by increasing the volume percentage of these plant fibers in the concrete, it is, therefore, rendered more thermally insulating [3].

We notice that in Fig. 5, the increasing humidification of the lightweight concrete studied results in a decrease in the thermal resistance, which negatively influences the insulating power of this material. This is very easily explained by the fact that water is an excellent conductor that induces a decrease in the thermal resistance of the concrete, replacing the air which is an excellent insulator [15, 16]. It is also found that the significant influence of the density on the thermal resistance of the lightened concrete, and thus on their thermal insulation power, the denser the material and the lower its thermal resistance.

It is clear that the determining factor in this decrease is the porosity of the material.

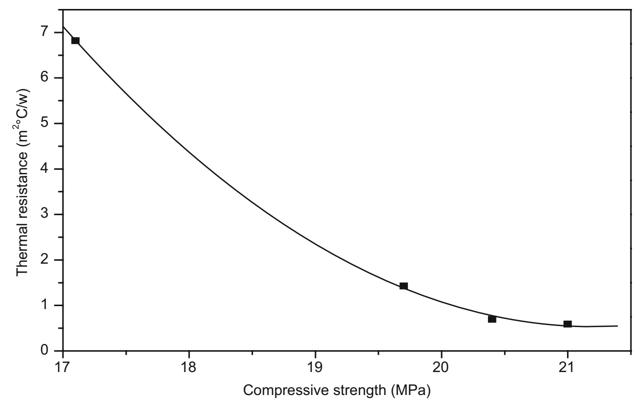

Fig. 6 Thermal resistance of lightened concrete variation as function of compressive strength for various samples

Thermo-mechanical effect

Concerning the results of the mechanical tests, the usual concretes generally have a strength of 20–30 MPa for mixtures mentioned above.

We obtain the compressive strengths cited in the following table:

Materials	Mix1 (0%)	Mix2 (1%)	Mix3 (2%)	Mix4 (3%)
Compressive strength	21	20.4	19.7	17.1

In terms of insulating and carrier material, the quality desired for a building material is a maximum thermal resistance, to which is added a high mechanical strength.

Our goal is mainly to improve the thermal qualities of concrete by integrating insulating materials during its mixing, while maintaining sufficient mechanical performance.

The variation of the thermal resistance as a function of the compressive strength shown in Fig. 6 allows us to characterize a domain where the values of these two characteristics are acceptable [17].

Conclusion

All the experimental results obtained during these tests make it possible to notice that the addition of vegetable fibers which are the olive pomace in our case seems to improve the thermal performances and cause a significant reduction of the density, indeed, the majority of the authors report that the addition of vegetable fibers to concrete has a positive effect on its thermal insulation capacity.

The essential observations that we can retain are:

– The unfavorable effect of the presence of water on the thermal insulation properties of materials.
– The thermal conductivity of the materials studied is strongly influenced by the volume density.
– The addition of olive pomace to the concrete during its preparation improves its thermal performance.
– Thermo-mechanical study, allowed us to present the curve of variation of the resistance to compression as a function of the thermal resistance. It can be considered as a criterion of choice of these materials for using them as carrier insulation.

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