Chapter 29
A Study on Thermo-Physical Properties of Building Materials: Concrete of Vegetable Fiber

Drifa Belkharchouche and Abla Chaker

Abstract The objective of this work is to make our contribution to the development of local resources, namely vegetable fibers (grignons of olives) of low cost and from a renewable source, and integrate it in a rational way in the field of construction. To date, these fibers remained undeveloped except for some traditional uses. A judicious choice of proportion additions (fiber) and technical implementation are considered. Particular attention is paid to the thermal characteristics (comfort and insulating properties of the habitat) and mechanical resistance which is a decisive criterion for the choice of a material in the construction. We determine the thermal conductivity of the materials studied with an experimental apparatus that allows us to make measurements of the thermal properties under actual operating conditions (temperature and humidity). Results show a significant reduction in the density and thermal conductivity with increasing dosage of vegetable fibers in the concrete. Thus, improving of the thermal insulation capacity is confirmed. The compressive strength decreases with increasing dosage of plant fibers.

Keywords Porous materials • Concrete of vegetable fiber • Thermo-physical properties • Box method

Nomenclature

ΔT	Temperature difference between indoor and outdoor environments (°C)
λ	Apparent thermal conductivity (W/m °C)
q	Heat flux (W)
S	Surface of the sample (m^2)
e	Thickness of the sample (m)
C	Heat loss coefficient (W/°C)

D. Belkharchouche (✉) • A. Chaker
Energy Physics Laboratory, University Constantine 1, Constantine, Algeria
e-mail: belkharchouchehayet@yahoo.fr

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W Water content (%)
V Voltage across the heater (V)
R Electrical resistance (Ω)

29.1 Introduction

Concrete is a heterogeneous composite of the resulting intimate mixture of cement, aggregates, water, and small amounts of adjuvant. These constituents are dosed so as to obtain, after curing, a solid product whose mechanical properties can be very superior to those of natural rocks. Insofar as cement is a hydraulic binder made from natural minerals, concrete can be considered as an artificial rock, but its fragility and density remain a handicap of its thermal and mechanical behavior, which is why it is reinforced with steel bars showing the tensile stresses. But instead of reinforcing concrete, and especially the thin parts which pose problems of size and protection of reinforcement, we can consider incorporating fibers throughout the material. Indeed different types of fibers are used as reinforcement of various materials to increase their mechanical strength and to improve their stability and thermal insulation. Before the development of composite materials, concrete is not the exception; researchers and fiber producers have thought of incorporating fibers as reinforcing materials in cement matrices [1]. Since then, the use of fibers in concrete has become a practice increasingly common and applications are developed through their proven ability by experience. The study allowed us to find new lightweight building materials and the valorisation of plant fibers and of low cost from renewable sources; such as grignons of olives, currently burned or used as animal feed.

29.2 Materials

After a deep investigation of the various existing local materials in Algeria and taking into account their availability and their cost, our choice is fixed on vegetable fibers to lighten the concrete. The proportions of additions are studied subsequently to develop new materials that can be insulating-carriers at competitive prices. Also thermophysical and mechanical characterization of these materials is carried out to confirm these choices. Natural fibers selected for this study are: The grignons of olives.

29.3 Experimental Determination of the Thermal Conductivity

The technique used to measure the thermal conductivity is called “box method” Fig. 29.1. It presents the advantage of a very simple implementation and the measurement precision is comparable to that obtained by conventional methods (hot wire, etc.) [2]. The box method allows to measure thermal conductivity of materials tested in permanent regime by realizing an energy balance of the system. 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, by creating a temperature gradient between its two faces. Indeed, the sample of parallelepiped form is placed between two enclosures, one of which is heated and the other is cooled, in such a way that the lateral flows are negligible. Once the permanent regime is established, the thermal conductivity is given by the Fourier law:

$$\lambda_{\mathrm{a}} = e \cdot q/S \cdot \Delta T = e/S \cdot \Delta T\left(V^2/R + C\Delta T'\right) \tag{29.1}$$

For measuring the moisture influence on the thermal conductivity, the used variable is the volumetric water content W. This is done by practicing successive weightings of the material from the partial saturation state until the dry state. Thus, the first wet measure is obtained after immersion of the material, for a few days, in water until its mass remains constant for 24 h (mass variation <0.1 %), which corresponds to the partial saturation state. For the intermediate wet measures, the first two drying operations are done in the ambient air with the measure of the corresponding values of thermal conductivity. Then, the drying is continued in a ventilated and regulated oven at 60 °C until the dry state. This is for obtaining certain continuity of the curves which give the variation of λ and a as function of volumetric water content.

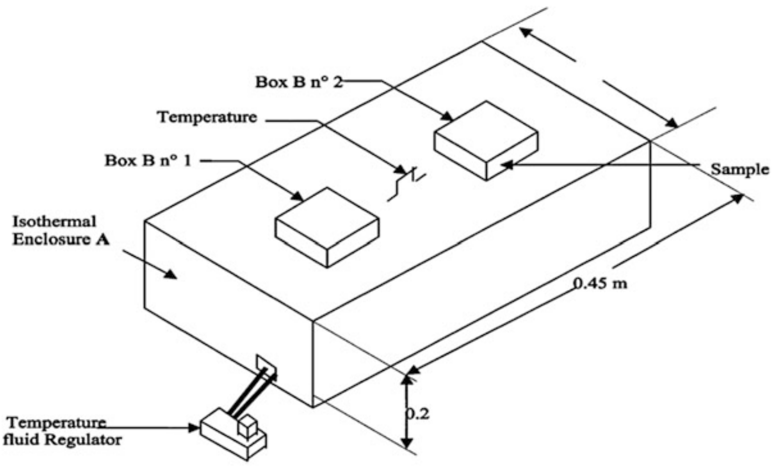

Fig. 29.1 Experimental setup of the box method

29.3.1 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 ($27 \times 27 \times 6$ cm^3) were used. For mechanical strength, the molds ($16 \times 4 \times 4$ 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 working on the same material. The specimens are preserved before and after turning out into the room test at a controlled temperature and humidity (Ta = 20 °C, RH = 60 %). These conditions correspond to a standard climate and allow reproducing real conditions of the use of the material [3].

29.3.2 Formulations

The method of composition of the classic concrete used is the one of BARON-LESAGE and GORISSE [4] for a ratio E/C (water on cement) minimally given; these methods aim at the optimization of the ratio S/G (sand on gravel) to obtain better workability [5].

– The weight of the fresh concrete is 2,350 kg/m^3.
– Good workability is obtained for a concrete having an S/G ratio of between 0.58 and 0.89.

To improve the thermal properties of concrete vegetable fibers (grignons of olives) were incorporated at rates ranging from 0 to 2 % (0, 1, 2 %). The sample thickness is 6 cm.

The aggregates used in the different mixtures were prepared from two sizes 5/8 and 8/15, sand (quarries) and cement portland CPJ45 Hamma Bouziane.

Water is the main component of agents that can degrade the material; we conducted a study on the influence of humidity on the thermo-physical properties of the material (Table 29.1).

Table 29.1 Mix design proportion

Materials	Mix 1 (0 %)	Mix 2 (1 %)	Mix 3 (2 %)
Cement (kg/m^3)	400	400	400
Aggregate (kg/m^3)	1,000	982	973
Sand (kg/m^3)	750	750	750
Water (kg/m^3)	240	270	290
Vegetal fiber (kg/m^3)	0	18	29

29.4 Results and Discussion

The observation of Fig. 29.2 shows that the thermal conductivity increases with the apparent density. It is evident that the critical factor in this growth is that the porosity of the material decreases as the material is dense.

Furthermore, the observation of these curves shows that the thermal conductivity of the concrete in the saturated state is higher than that of the concrete in the dry state. This is explained by the fact that by adding water to the dry concrete, we replace a component of low thermal conductivity (thermal conductivity of air is approximately 0.026 W/m °C) by forming a higher conductivity (the thermal conductivity of water equal to 0.6 W/m °C), 30 times higher than that of the dry air. This results in an increase of the overall thermal conductivity of the material [6, 7].

Figure 29.3 shows the shape of the experimental curves expressing the variation of the apparent thermal conductivity as a function of water content for different fiber percentages; measurement of the average temperature is between 16 and 25 °C. These graphs highlight the heat-insulating power and water absorption of these composite materials. We also note that the apparent thermal conductivity increases significantly with the volumetric water content without having a linear variation. This has been observed on other materials such as plaster [8]. The incorporation of fibers in the concrete, during its mixing, improves its thermal insulation power [9].

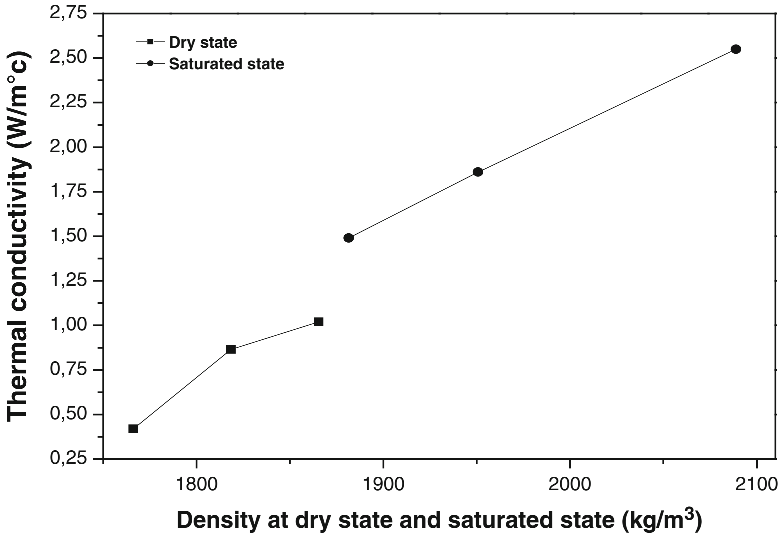

Fig. 29.2 Influence of density in the dry state and saturated state on the thermal conductivity

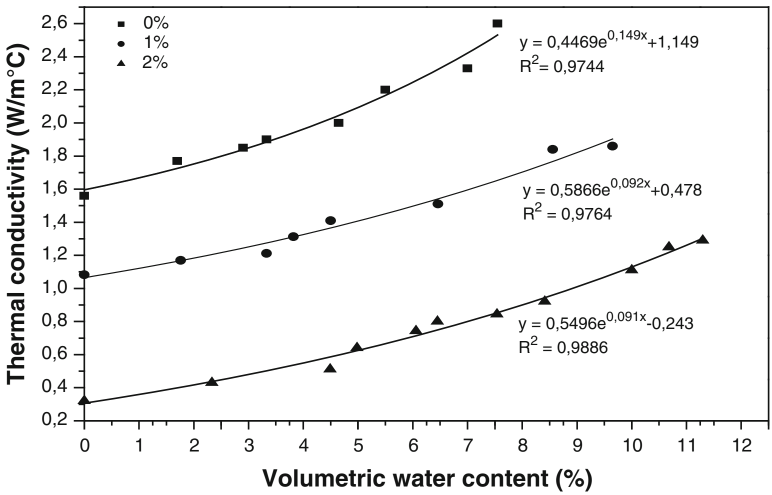

Fig. 29.3 Variation of thermal conductivity as a function of water content for different percentages of fiber

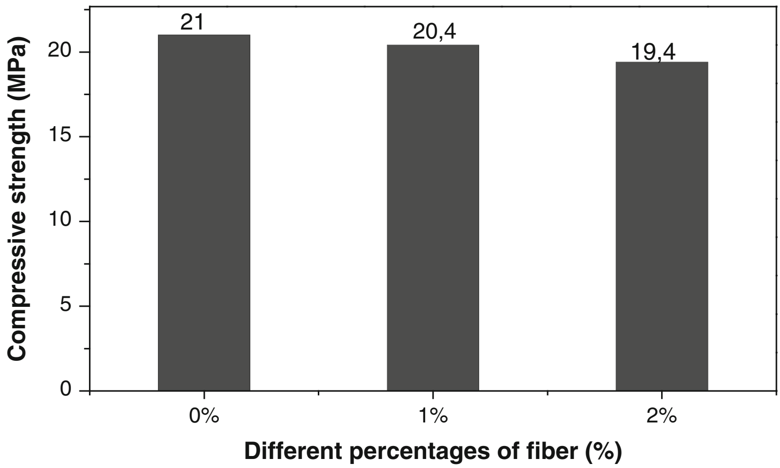

Fig. 29.4 Variation of the compression strength as a function of different percentages of fiber

29.4.1 Compressive Strength

The mechanical compression strength after 28 days is obtained by crushing test pieces with a hydraulic press. In Fig. 29.4, we have represented the variation of the compressive strength as a function of different percentages of fiber. Then, in Fig. 29.5 is shown the variation of the compressive strength as a function of density. It is clear that the gain of the light is accompanied by loss of mechanical strength compression, due to the decrease of the compactness of the material.

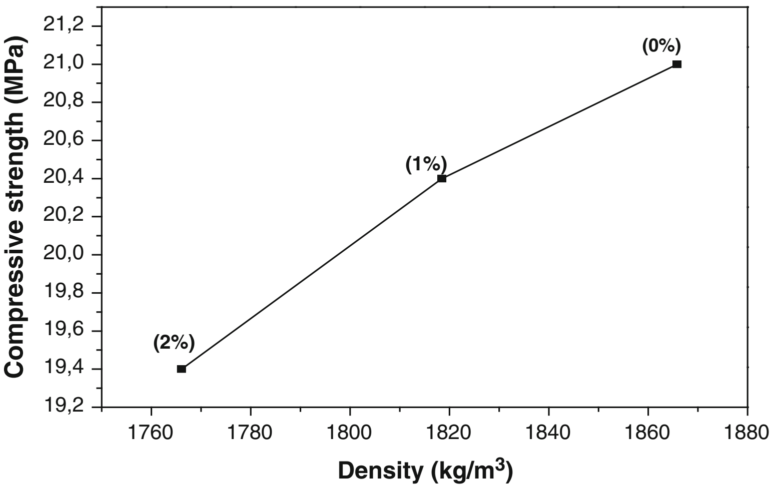

Fig. 29.5 Variation of the compression strength as a function of density

29.5 Conclusion

All the results obtained in these thermal and mechanical tests allow to note that adding fiber seems slightly improve the thermal and mechanical performance. It appears in particular a decrease in thermal conductivity with increasing fiber content, on the moisture content, we have shown a very significant increase in the thermal conductivity at low water contents and then a slower increase to values average and again more rapidly to levels close to the saturation state. Nevertheless to refine our judgment proportions of other fibers, most important and specific provisions of the fibers in the material should be considered and studied.

The thermal properties of the composite material are not alone a selection criterion, we must also take into account the state of the material, its availability and its mechanical bending of the effect of other additions to the thermal and mechanical behavior of materials developed. A more general study on its thermomechanical properties is in progress.

References

1. Khedari J, Watsanasathaporn P, Hirunlabh J (2005) Development of fibre-based soil–cement block with low thermal conductivity. Cement Concr Compos 27(1):111–116
2. Al-Ajlam SA (2006) Measurements of thermal properties of insulation materials by using transient plane source technique. Appl Therm Eng 26:2184–2191
3. Kriker A, Bali A (2008) Durability of date palm fibres and their use as reinforcement in hot dry climates. Cement Concr Compos 30:639–648

4. Baron J, Lesage R (1976) La composition du béton hydraulique, du laboratoire au chantier. Rapport de recherche LCPC No. 64
5. Rossi P. Les bétons de fibres métalliques, presses de l'école nationale des Ponts et chaussées, ISBN2-85978-2923
6. Taoukil D et al (2013) Moisture content influence on the thermal conductivity and diffusivity of wood concrete composite". Construct Build Mater 48:104–115
7. Bal H, Jannot Y (2013) Measurement and modelisation of the thermal conductivity of a wet composite porous medium: laterite based bricks with millet waste additive. Construct Build Mater 41:586–593
8. Cherki A-b, Remy B (2014) Experimental thermal properties characterization of insulating cork-gypsum composite. Construct Build Mater 54:202–209
9. Bal H, Jannot Y (2012) Water content dependence of the porosity, density and thermal capacity of laterite based bricks with millet waste additive. Construct Build Mater 31:144–150