Thermal Insulating Characteristics of Cork Agglomerate Panels in Sustainable Food Buildings

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Abstract. Over the last few years, the building industry has been focusing on research, on the construction of passive houses and on the use of natural, local materials that are non-toxic, recyclable and can assure high thermal insulation. Cork is a natural material whose qualities have been known since ancient times and which fully meets sustainability requirements. Cork granulate is a sustainable solution that recycles a waste product, which substantially keeps the characteristics of the original material, turning it into a resource for manufacturing new products, such as insulating panels made up of cork agglomerate, which are increasingly used in the building sector. In this paper, certain thermophysical parameters of six panels of cork agglomerate are evaluated. The tested panels of granulated cork showed thermophysical characteristics similar to those of the cork bark and even highlighted a higher diffusivity value than natural cork. Ultimately, it may be assumed that the panels of agglomerated cork are a suitable and sustainable solution particularly for the thermal insulation of buildings in hot climate areas and where a healthy environment is required, e.g. where agri-food products are processed and stored.

Keywords: Cork agglomerate, insulation, agri-food, thermal conductance.

1 Introduction

Over the last few years, the building industry has been focusing on research, on the construction of passive houses and on the use of natural, local materials that are non-toxic, recyclable and can assure high thermal insulation (Barreca 2012). Cork is a natural material whose qualities have been known since ancient times and which fully meets sustainability requirements. It is obtained from the bark of an oak, the *Quercus suber,* which is widespread in Portugal, Spain, North Africa and in a few areas of Italy. Its characteristics have long been known: already in the 1st century, in his *Naturalis Historia,* Pliny the Elder recommended to use it for its high insulating capacities. In the studies on plant anatomy, cork plays a crucial role since it was the first plant tissue to be examined under a microscope, described and drawn (Hooke 1664). It is a very homogeneous and compact parenchymatous tissue with a

Proceedings of the 7th International Conference on Information and Communication Technologies in Agriculture, Food and Environment (HAICTA 2015), Kavala, Greece, 17-20 September, 2015.

oneycomb-like structure (Pereira, 1998). This peculiar structure and the suberization of its cell walls make them similar to watertight compartments, owing to the presence of a large amount of gas in the suberose cells. As a result, they are also considerably light, very elastic, impermeable to liquids and gases and thermally and sound insulated (Palma 1986). Finally, cork is strong and quite resistant to the enzymes secreted by parasites, since suberin is one of the most resistant organic substances. Though it is widely grown, the regeneration of its bark is slow: it takes over 10 years on average to regenerate after the first barking, which usually takes place 20-25 years after the birth of the plant. That is why cork, and above all first-class cork, is a valuable material. High quality cork is mainly used to produce bottle stoppers and, owing to the manufacturing process, over 75% of it becomes a waste product (Colagrande, 1996). On the other hand, a large amount of waste cork comes from industry, from forest cleaning and pruning and from waste selection. Such a material is then recycled and triturated to obtain the so-called cork granulate (ISO 1997; 1972).

Cork granulate is commonly used in the building sector as bulk material in the air gaps of curtain walls; it is added to plaster to produce thermal insulating panels (Cherki et al., 2014); or mixed with asphalt (Pereira 2013) or with lightened mortar (de-Carvalho et al. 2013). Cork granulate is a sustainable solution that recycles a waste product turning it into a resource for manufacturing new products (Rives et al. 2012). Recently, insulating panels made of agglomerated cork have been introduced in the building sector. They are offered in various versions depending on the glue used, on gradation and specific density. In particular, since the type of glue used to make the panel influences the final mechanical and thermal behaviour, various types of synthetic and natural glues were tested (urethane, melaminic and phenolic resins) (Gil 2009). However, a special building method allows using only the typical resin of cork (suberin) to glue granules. Such a method entails overheating granules (or using high-frequency ultrasounds) to soften the suberin and the lignin that make cork granules expand and bond together. In this paper, certain thermophysical parameters of six panels of cork agglomerate are evaluated. Different constituent characteristics of the panels, such as grain size distribution, density and thickness, were taken into account in order to evaluate how they may influence thermal insulating performances.

Nomenclature

Λ_t	conductance to time t [$Wm^{-2}K^{-1}$]
$q(t)$	instantaneous density of heat flow rate at time t [Wm^{-2}]
$T_h(t)$, $T_C(t)$	instantaneous temperature at time t on the internal and external surface of the sample at time t [K]
ΔQ	shift heat flow [W]
ϱ	bulk density [kgm^{-3}]
V	volume [m^3]
c	specific heat capacity [Jkg^{-1} K^{-1}]
ΔT	temperature shift [K]
Δt	time shift [s]

$Q_h(t), Q_c(t)$	heat flow across the internal and external surface of the sample at time t [W]
d	thickness of sample [m]
A	surface area of sample [m^2]

2 Materials and Method

The six analysed panels are commonly sold on the Italian market to insulate walls and roofs. Five panels are made of blond cork and one is made of expanded toasted brown cork (dark agglomerate). (fig. 1). Three 0.45x0.45 m samples were taken from each panel to test gradation, density, thermal conductivity, heat capacity and thermal emissivity. In order to apply Fourier's law, which is essential to calculate the thermophysical properties of materials, agglomerated cork panels thicker than the average size of the basic elements of the material were considered (Bonacina et al. 1984).

Fig. 1. Testing specimens of agglomerate cork panel.

1. Size analysis and bulk density

Panels were characterized by three different gradations. A size analysis (ISO 2030) was performed through mechanical sieving by taking three 100g samples from each bulk gradation (BL 1, BL 2, BR) and using mesh apertures conforming to the series ISO/R 40/3 and a balance with accuracy 0.1 g. The calculated average values allowed constructing the relative cumulative percentage retention curves (Fig. 2).

The bulk density was measured by averaging the measurements taken on the three samples of each panel according to ISO 2189. The size of the samples was measured to the nearest millimetre and at constant temperature and environmental humidity.

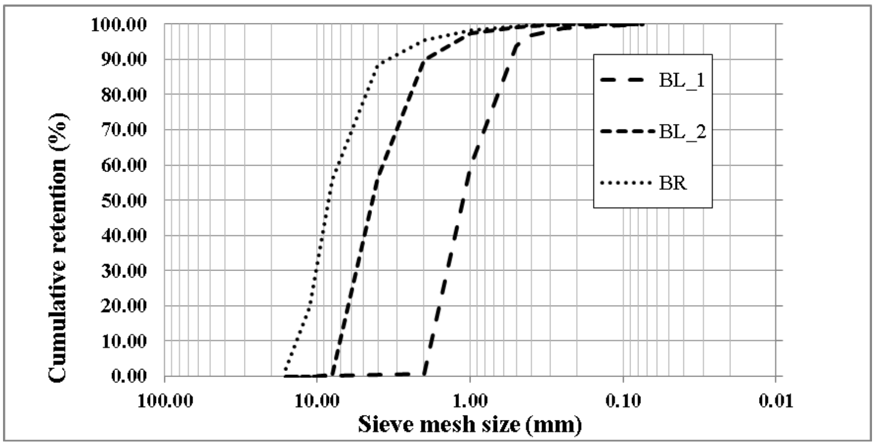

Fig. 2. The cumulative percentage retention curves for the three different cork granular materials. Semi granular scale.

Table 1. Physical properties of investigated samples.

Sample	Granulate type cork	Thickness [m] · 10^{-2}	Weight [kg]	Volume [m^3] · 10^{-6}	Bulk density [kgm^{-3}]
A	BL1	1.38	1.06	2872.06	369.35±0.01
B	BL1	1.10	0.86	2283.38	375.95±0.02
C	BL1	2.90	2.35	6035.48	389.71±0.01
D	BL2	2.10	0.65	4467.02	145.85±0.01
E	BL2	2.90	0.96	6115.26	157.02±0.01
F	BR	1.95	0.53	4845.79	108.70±0.01

2. *Thermal conductance*

A testing apparatus, similar to the one the authors had employed in a previous work (fig. 2) (Barreca and Fichera 2013), was used to implement the procedure described by ISO 9869, *Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance*, and to evaluate the thermophysical properties of the panels under conditions similar to those of their actual use, i.e. for the thermal insulation of walls in buildings located in hot climate areas. This simple and easily portable apparatus is composed of a cold insulated box whose internal temperature ranges from 26° and 2° C, thanks to a refrigeration system. The panel to test is fixed to a side of the box and the box is placed in a confined environment with a temperature of 20-40°C controlled by an automatic heating system that turns on at preset intervals to simulate the dynamic variations of the external temperature in the hot seasons of the Mediterranean climate. Four surface temperature sensors and a heat flowmeter (HFM) were attached at the centre of the inner and outer faces of each sample to measure continuously the heat flow passing in both directions. With a view to limiting mutual interferences, sensors were placed in a symmetrical but offset position.

All the sensors of temperature, of surface heat flow, of air temperature and humidity of the environment inside and outside the cold box are networked by data loggers, which acquire and store the values taken at intervals of 300 s. A thermal infrared camera allowed verifying the homogeneity of the surface temperatures of the samples as well as possible heat losses or hidden sources of thermal radiation. After 72 hours of measurements and, however, after checking certain conditions imposed by ISO 9869, such as a constant difference in temperature between the hot and cold spaces higher than 10°C and a heat flow >5 W/m^2, the instantaneous conductance was calculated by means of (1)

$$\Lambda_t = \frac{q(t)}{T_h(t) - T_c(t)} \tag{1}$$

The final conductance value was obtained by applying the progressive average method to (1) throughout the testing period.

Table 2 shows the values obtained for each panel.

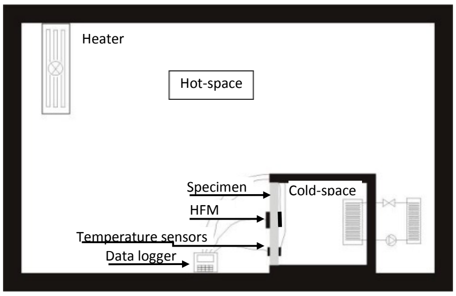

Fig. 2. Testing apparatus used for the insulation analyses on the samples.

3. Heat capacity

The specific heat capacity is a thermophysical parameter particularly significant for insulating materials since, together with density and thermal conductivity, it enables to calculate the thermal diffusivity of the material, which is a peculiar parameter of the speed of temperature variation between the two faces of a wall. Moreover, it allows calculating the phase lag of the thermal wave, a phenomenon extremely useful to mitigate temperatures inside buildings in hot climate areas.

Considering the limited thickness of the samples, their heat capacity was measured through a simplified procedure by applying the transient method (Wakili et al. 2003) to the apparatus described above. The temperature variation inside the confined environment, which occurred at regular 2-hour intervals, led to a cyclic, transient heat transfer. As a matter of fact, the variable heat difference between the confined environment and the inside of the cold box originated a variable heat flow that passed through the tested sample and was measured when entering and exiting it by means of the two heat flowmeters placed on both faces. The following can be derived from the general conduction equation in finite terms:

$$\Delta Q = \rho V c \, \Delta T / \Delta t \qquad (2)$$

As a result, referring to the time interval, which corresponds to the turn on/off cycle of the heating system outside the cold box, and assuming a linear temperature variation inside the sample, the following is obtained from (2):

$$c = \sum_{t=0}^{t=\Delta t} [(Q_h(t) - Q_c(t)) \, \Delta T_t] \Delta t \rho A d \qquad (3)$$

Specifically, the values of heat capacity shown in the table were obtained from the average of three samples of the same panel for a turn on/off interval of the heating system of 120 min.

Assuming a one-dimensional heat flow, numeric check of the data from the measurements taken with the testing apparatus were carried out with an RC-model by means of the system identification technique of LORD 2000 (L.Ljung 1999). Fig. 3 shows the model of the system.

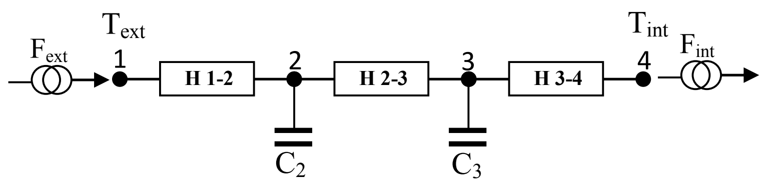

Fig. 3. RC-model of the testing apparatus

By analogy, the RC-model shown in Fig. 3 represents the thermophysical behaviour of the tested sample. In particular, the sample was schematized by two internal nodes (2 and 3) and by two edge nodes (1-4). Resistances H 1-2, H 2-3, H 3-4 represent heat resistance, while capacities C2 and C3 represent the overall heat capacity of the sample. Node 1 was associated to the values of the flows and temperatures measured on the outer face of the sample, while node 4 was associated to the values of the flows and temperatures measured on the inner face of the cold box. The software LORD solves the system considering the values measured during the transient period. Particularly, the temperature measured at node 4 and the flow measured at node 1 were considered as output values for the correction of the calculated values.

4. Emissivity

Infrared thermography was used to calculate the emissivity of the panels. In particular, samples were heated at a temperature of about 40±5°C (fig.4.) by means of electrical plates positioned at the centre of their faces, where a strip of black dielectric material with emissivity equal to 0.97 was also applied. The surface temperature of the dielectric material and of the sample was measured with a contact thermometer. Then, the emissivity value of the cork agglomerate sample was obtained through a software programme for the analysis of infrared images assuming that the infrared measured temperatures coincided with the contact measured ones. The analysis of the emissivity values of each sample showed a significant difference between the faces of the same sample. Such a difference may be due to the different surface finish. Actually, because of the different granulate sedimentation during the compression and heating phases and the consequent expansion of the panel, the finest part of the granulate settles more on one of the two faces, thus determining a more compact surface and a lower presence of gaps.

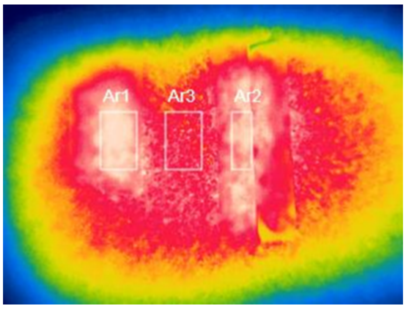

Fig. 3. Thermal infrared image of a sample of panel

Table 2. Thermal properties of investigated samples

Sample	Conductance $[Wm^{-2}K^{-1}]$	Conductibility $[Wm^{-1}K^{-1}] \cdot 10^{-1}$	Capacity $[JK^{-1}]$	Diffusivity $[m^2s^{-1}] \cdot 10^{-8}$	Emissivity
A	5.51±0.69	0.77±0.10	3033.50±382	7.26±0.91	0.93±0.005
B	7.52±0.95	0.83±0.10	2457.20±309	7.70±0.97	0.91±0.004
C	2.79±0.35	0.81±0.10	4644.60±585	10.5±1.32	0.93±0.000
D	2.52±0.32	0.52±0.07	2491.90±314	9.38±1.18	0.94±0.021
E	1.76±0.22	0.54±0.07	3099.70±390	10.6±1.33	0.92±0.001
F	2.27±0.29	0.47±0.06	2452.70±309	7.75±0.97	0.93±0.013

3 Results and discussions

Table 2 shows the results obtained. The analysis of the values demonstrates that the cork agglomerate panels have thermophysical characteristics similar to those of natural cork (Silva et al., 2008), which, however, has a value of thermal conductivity slightly lower (0.045 $Wm^{-1}K^{-1}$) than the average value of the cork agglomerate panels (0.065 $Wm^{-1}K^{-1}$), but a heat capacity definitely lower (350 $Jkg^{-1}K^{-1}$) than the average value of the specific capacity of agglomerate panels (3370 $Jkg^{-1}K^{-1}$) and a value of thermal diffusivity ($1.00 \cdot 10^{-6}$ m^2s^{-1}) one order of magnitude higher than the average of the cork agglomerate panels ($1.04 \cdot 10^{-7}$ m^2s^{-1}). As mentioned above, the thermal diffusivity value of an insulating material is one of the most important indicators of its thermal resistance, since it measures heat propagation through a wall of a temperature field under non steady-state conditions.

4 Conclusions

In this study, a simple method was used to measure conductivity and specific heat capacity by simulating the transient situation which occurs under real life conditions in hot Mediterranean climate areas. These values are particularly important to choose and properly apply the insulating material considering the external environmental conditions, typical of the place where the building is located, and the internal environmental conditions that should be assured. Therefore, the method was applied to evaluate the thermal performances of panels of cork agglomerate, a material that is used for the thermal insulation of premises for the temperature-controlled storage of agri-food products because it is not toxic. The values obtained confirmed the good insulating characteristics of the granulate panels, which, in some respects, are even better than those of natural cork are. In particular, cork agglomerate panels have a lower commercial value because, in most cases, cork granulate is obtained from recycled material.

Acknowledgment. The research activity illustrated in this paper was funded by the Region Calabria within the project PSR (Rural Development Programme) 2007/2013 Measure 124 – Aid application n.94752170756 - project SUBERWALL

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