Journal of Building Engineering 7 (2016) 183–193

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

Experimental study and modeling of hygro-thermal behavior of polystyrene concrete and cement mortar. Application to a multilayered wall

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ARTICLE INFO

Article history:
Received 22 February 2016
Received in revised form
7 May 2016
Accepted 13 June 2016
Available online 15 June 2016

Keywords:
Polystyrene concrete
Cement mortar
Heat and mass transfer
Multilayered wall

ABSTRACT

Polystyrene concrete is used to reduce energy consumption in buildings and to recycle some waste. However, one records a lack of knowledge of its hygro-thermal characteristics. This study involves two aspects: the first aspect is to measure the thermo-physical properties of polystyrene concrete and cement mortar. The second aspect is to study the hygro-thermal behavior of these highly heterogeneous materials subjected to external excitations. Numerical and experimental approaches are used. For both approaches, the ambient conditions have a direct impact on the behavior of the walls. The studies are therefore conducted in varying climatic conditions on blocks placed in an experimental bench. In parallel to the experimental approach, a model representative of heat and mass transfer in materials: capillaro-porous media (composite concrete) and multiphasic media (coating of cement), is developed in order to predict hygro-thermal behavior of the wall. A numerical simulation of the hygro-thermal behavior is performed for a multilayered wall. Comparison is carried out when the discontinuity phenomenon, at the interface between two porous materials, is taken or not into account. The results show the advantage of replacing the ordinary concrete by a polystyrene concrete in constructions. They also show the importance of taking into account the discontinuity of the moisture content at the interface of materials that make up a multilayered wall.

Subcripts/Supercripts

a	air
l	liquid
v	vapor
s	solid
I	interface

1. Introduction

Builders are interested, above all, by the use of efficient materials in terms of mechanical strength and durability. The aspects of comfort are generally processed last by the use of different materials (thermal and acoustic insulation, vapor barrier…). The cost of construction increases. To minimize cost and save energy, it is necessary to implement adequate thermal insulation of building walls. Actual trends in construction materials are to promote composites able to fulfill several purposes. The addition of a coating, or surface paint, complements these composite products and improves the performance of an entire wall. Light concretes can overcome the disadvantages of conventional concrete retaining its mechanical performance. They have new physical properties (mechanical, hygro-thermal, acoustic…). In the literature, studies show the advantage of adding materials, having different physical properties, to conventional blends [1,2]. These materials must be economically viable and in agreement with comfort and sustainable development [3–5].

In this context, this study deals with the characterization of a composite concrete loaded by polystyrene chips which, has interesting characteristics notably, a low thermal conductivity. The use of this material is intended to improve the thermal insulation, to reduce the thermal inertia and recycle some domestic or industrial waste.

This study is conducted on two samples subjected to variations in external conditions. The first is concrete polystyrene and the second is cement mortar. The characterization is performed on

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http://dx.doi.org/10.1016/j.jobe.2016.06.007
2352-7102/

Nomenclature

c	specific heat, J kg^{-1} K^{-1}
D_T	mass transfer coefficient due to the temperature gradient, m^2 s^{-1} K^{-1}
D_S	mass transfer coefficient due to the saturation gradient, m^2 s^{-1}
D_{Tl}	liquid phase transfer coefficient due to the temperature gradient, m^2 s^{-1} K^{-1}
D_{Tv}	vapor phase transfer coefficient due to the temperature gradient, m^2 s^{-1} K^{-1}
D_{Sl}	liquid phase transfer coefficient due to the saturation gradient, m^2 s^{-1}
D_{Sv}	vapor phase transfer coefficient due to the saturation gradient, m^2 s^{-1}
Fcl	latent heat flux, W m^{-2}
Fcs	sensible heat flux, W m^{-2}
h_c	convective heat transfer coefficient, W m^{-2} K^{-1}
h_r	radiative heat transfer coefficient, W m^{-2} K^{-1}
h_m	mass transfer coefficient, m s^{-1}
j_v	vapor flow, kg m^{-2} s^{-1}
L_v	latent heat of vaporization, J kg^{-1}
M	mass molar, kg mol^{-1}
P_c	capillary pressure, Pa
Q	heat flux density, W m^{-2}
R	gas constant, J mol^{-1} K^{-1}
RH	relative humidity, %
S	saturation ratio
T	temperature, K or °C
t	time, s
w	mass moisture content, kg of water/kg of porous material

Greek symbols

ε	porosity
ρ	density, kg.m^{-3}
λ	thermal conductivity, W m^{-1} K^{-1}
θ	volume moisture content

both materials. A numerical simulation is then, performed on a multilayered wall composed of polystyrene concrete covered with a coating of cement on either side.

2. Experimental and Results

Cement mortar is composed by cement, sand and water. Concrete is composed by the same ingredients mortar with an addition of polystyrene chips to the mixture with various percentages. Table 1 shows the nomenclature of prepared samples. The selected compositions are described in Table 2. Percentage in mass of the ingredients is calculated based on the total mass of the sample.

2.1. Density

The influence of the incorporation of polystyrene chips on the density of concrete is studied. The results obtained are illustrated in Fig. 1. The density of concrete reduces when the percentage of chips increases. The density of the cement mortar (MP0) (0% polystyrene) is 2200 kg/m^3, while the (MP4) concrete (4% polystyrene) is 1220 kg/m^3, which corresponds to reduction of 44.5%. The decrease is not linear.

The density of concrete and mortar depends on several factors such as age of the composite, proportion of aggregates, water/cement ratio, amount of cement, temperature, method of preparation of samples, etc. [6].

2.2. Thermal conductivity

The method of guarded hot plate is used. The measurements are performed in steady state [7]. Samples are permanently in the free air, under natural conditions of temperature, pressure and humidity of the room of measurement.

Table 1
Nomenclature of prepared samples.

Designation	Denomination	Percentage of polystyrene compared to the mass of cement
MP0	Cement mortar	0%
MP1	Polystyrene concrete	1%
MP2	Polystyrene concrete	2%
MP3	Polystyrene concrete	3%
MP4	Polystyrene concrete	4%

Table 2
Composition of studied materials.

Mass fraction kg/kgx100 (%)	Cement	Sand	Water	Polystyrene	Water/Cement
MP0	22.22	66.67	11.11	0.00	50
MP1	22.17	66.52	11.09	0.22	50
MP2	22.12	66.37	11.06	0.44	50
MP3	22.08	66.23	11.04	0.66	50
MP4	22.03	66.08	11.01	0.88	50

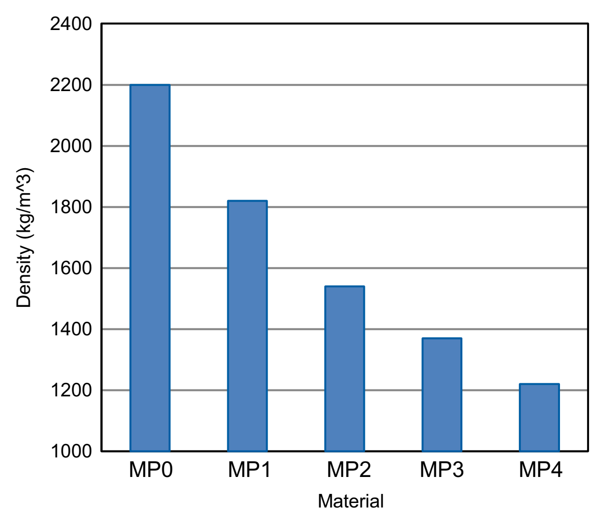

Fig. 1. Variation of concrete density according to the type of polystyrene concrete .

2.2.1. Influence of density

The apparent thermal conductivity increases proportionally with the apparent density of the material (Fig. 2). It represents the equivalent conductivity of the three phases (solid, liquid and gas) which constitute the porous material. Thermal conductivity of the light porous material is smaller than that of heavy material. However, more the material is compact; more it comprises solid elementary particles able to transport thermal energy by