

# Moisture transfer modelling in polystyrene mortar with consideration of sorption hysteresis

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**Abstract.** The walls of buildings experience heat, air and moisture transfers. These transfers have a significant influence on indoor climate, since they affect the value of temperature and relative humidity in houses. High levels of humidity lead to pathologies in the buildings, and influence the air quality and the hygrothermal comfort of the occupants. In this work, a numerical analysis of the behaviour of polystyrene mortar under hydric solicitations was led. The simulations were held using Comsol Multiphysics and MATLAB. There were two different moisture transfer models used in this work: the first one took into account sorption hysteresis phenomenon, and the other one did not. The computed results showed that considering sorption hysteresis in modelling the hydric behaviour of the material allows obtaining more accurate results comparing to a model that does not consider hysteresis.

## 1 Introduction

Currently, building sector is the most energy-consuming sector in the world [1,2], and in particularly in France where it represents 43% of the total energy consumption [3]. This led to thoughts about the improvement of the insulation in buildings through innovative building materials, in the context of promoting energy efficiency. Polystyrene concrete is a good alternative to usual building materials in modern construction applications. It is considered as an eco-material and helps improving the technical, economical and environmental aspects of the construction sector. Polystyrene concrete significantly reduces the load of the construction due to its low density. It is characterized by its lower thermal and acoustic conductivity, and its improved durability properties [4,5].

Plenty of works have been investigating thermal, mechanical and durability properties of polystyrene concrete [6 – 9], and some studied its microstructure [10 – 13]. Only few works were interested in the hygrothermal behaviour of this kind of building materials [14,15], despite its increasing use in the construction sector as curtain walls, coating panels or floor coverings.

Sorption hysteresis phenomenon characterizes the behaviour of a porous material that tends to have different water content at equilibrium whether it is in adsorption or desorption phase (fig.1). It results in obtaining different sorption curves in adsorption and desorption, and has great effect on the kinetics of

moisture transport and storage. It has been proved in the past that it is necessary to consider this phenomenon in modelling the hygrothermal transfers in porous materials [16], especially that it occurs in the whole relative humidity range (up to 100%) [17].

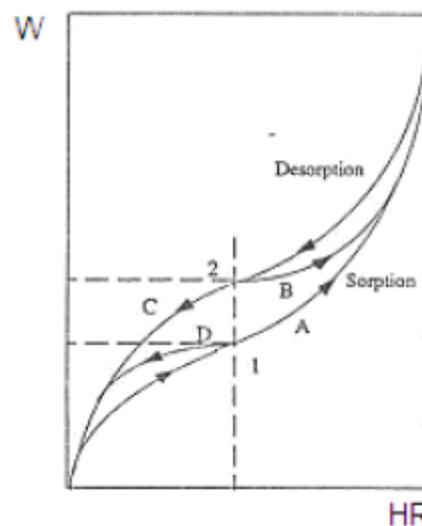


Fig. 1. Sorption hysteresis curves [18]

The aim of this paper is to elaborate a moisture transfer model describing the hygrothermal behaviour of polystyrene concrete, and to take into account the influence of the sorption hysteresis phenomenon. First, we present the material and simulation conditions, and then the model used to describe sorption hysteresis. The

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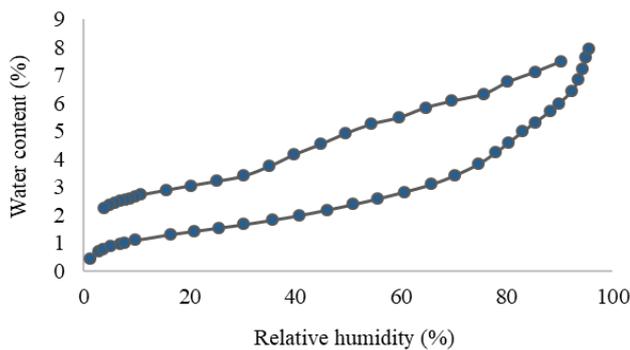
obtained results are compared to the results of a non-hysteresis model, to show the influence of the phenomenon.

## 2 Materials and procedure

The material studied in this work is a polystyrene mortar made of cement and polystyrene aggregates, mixed respecting a water/(cement + polystyrene) mass ratio of 0,32. The cement is of type CEM II and the aggregates are spherical expanded polystyrene beads, and their diameter is in between 2 and 3 mm.

The main sorption isotherms shown in fig.2 are determined using the Belsorp aqua-3 that is based on a volumetric method, which determines the volume of gas adsorbed by the material from the change in gas pressure. That method was proved more precise than the gravimetric method for lightweight materials that do not adsorb a lot of water [20].

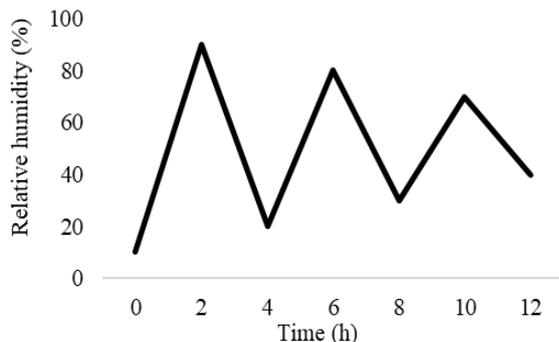
The input parameters are some of the intrinsic properties of this material. The properties needed for this study are the density, the water vapour permeability, and the main adsorption and desorption curves.



**Fig. 2.** Main adsorption and desorption curves of polystyrene mortar

In the numerical simulations, the sample was considered insulated on all sides except one surface. The initial conditions of the material are 50% of relative humidity and 23°C.

The loading solicitations of relative humidity is explained in the figure below (fig.3):



**Fig. 3.** Loading protocol

Water vapour transport is given by combining Fick's law and the conservation of mass equation:

$$\rho (du/dt) = \text{div}[D_m(\nabla u)] \quad (1)$$

With  $\rho$  the density of the material,  $u$  the moisture content and  $D_m$  the diffusion coefficient.

The sorption hysteresis phenomenon is described by Carmeliet model [19] that is a physical based model and uses the inkbottle concept. The model expresses an accessibility function determined from the main sorption isotherms and calculates the moisture content of the primary curves. Water content for the adsorption curve of rank  $i$  is expressed by the equation (2), and water content for the desorption curve of rank  $i$  is expressed in equation (3).

$$u(\phi, i) = u_{i-1} + [1-A(\phi_{i-1})][u_{ads}(\phi) - u_{ads}(\phi_{i-1})] \quad (2)$$

$$u(\phi, i) = u_{i-1} - [1-A(\phi)][u_{ads}(\phi_{i-1}) - u_{ads}(\phi)] \quad (3)$$

The coordinates  $(\phi_{i-1}, u_{i-1})$  represent the inversion point between the desorption curve of order  $i-1$  and the adsorption curve of order  $i$ . The accessibility function is given by the equation (4).

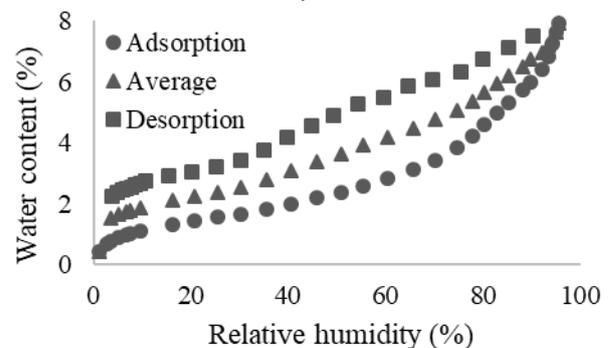
$$A(\phi) = [u_{des}(\phi) - u_{ads}(\phi)] / [u_{sat} - u_{ads}(\phi)] \quad (4)$$

The equation describing the water vapor transport is implemented in Comsol multiphysics software environment [21], and the algorithm calculating the water content in the primary adsorption and desorption curves considering hysteresis is computed in MATLAB [22]. The two softwares are then coupled in order to obtain the numerical hydric behavior of the material with the influence of sorption hysteresis.

The non-hysteresis model uses the equation expressing the water vapor transport only, without coupling it with Carmeliet model. The numerical computations are only done on Comsol environment, based on the diffusion phenomenon.

## 3 Results and discussion

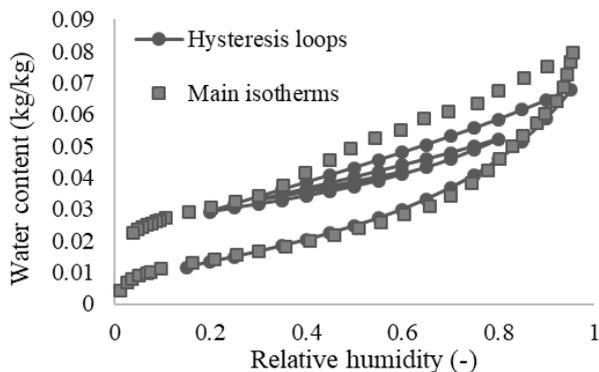
In this section, we present the computation results. First, we are presenting the input data that are the main and primary adsorption and desorption curves. Afterwards, we present the evolution of water content profiles obtained with the hysteresis model and the model that does not take into account hysteresis.



**Fig. 4.** Main adsorption, desorption and average curves

Previous models generally neglect hysteresis and use the main desorption isotherm to model moisture transport for both drying and wetting processes [23-25]. That is

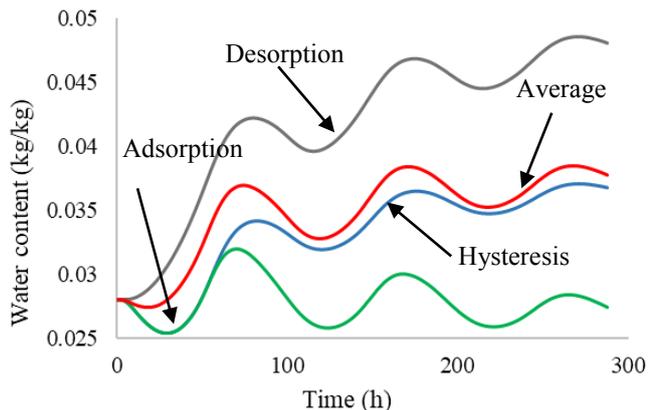
why we are determining the water content at each time using three different ways. The first one is based on the use of the main adsorption curve only, which means that for every relative humidity in the loading protocol, the water content is the corresponding value in the main adsorption curve. The same logic is used for the main desorption curve, where the water content corresponding to each relative humidity value is found on the main desorption curve. The main average curve is constituted of the mean values of water content that are an averaging of the main adsorption and desorption curves. The main adsorption, desorption and average curves used to determine the water content in each case are presented in the fig.4.



**Fig. 5.** Modelled hysteresis loops

The model that considers sorption hysteresis describes the intermediate curves as loops included inside the main adsorption and desorption curves that are considered as an envelope. The evolution of the water content in time is shown in fig.5.

The water content profiles obtained through the computations on Comsol multiphysics are presented in fig.6. The profile is shown for a point in the middle of the sample.



**Fig. 6.** Water content profiles in the middle of the sample

As can be seen on the figure, using only the adsorption curve underestimates the water content while using desorption curve overestimates it. Modelling the moisture transport using the average curve is reasonably estimating the water content, but the variations are not well expressed and it shows a decrease in the water content at the beginning, which is unjustified because the relative humidity is increasing at first.

The hysteresis model is the most accurate for expressing the water vapour transport in polystyrene mortar. It considers the water accumulation in the porous materials because of the inkbottle effect and does not show the decrease in water content at the beginning.

## 4 Conclusion

In this work, we investigated the hydric behaviour of polystyrene mortar under cyclic solicitations. Numerical simulations were led to model the hydric response of the material to the relative humidity variations, and we used both a hysteresis model and a non-hysteresis one to compute the results.

The model that considers sorption hysteresis shows a better agreement with the hydric behaviour of polystyrene mortar, while the non-hysteresis model presents some discrepancies.

Further work should be carried out to improve the model by taking into consideration phenomena other than water vapour diffusion.

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