Construction and Building Materials 65 (2014) 507–517

Contents lists available at ScienceDirect

Construction and Building Materials

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

Drying behaviour of calcium silicate

M. Van Belleghem [a,*], M. Steeman [b], A. Janssens [c], M. De Paepe [a]

[a] Ghent University, Department of Flow, Heat and Combustion Mechanics, Sint-Pietersnieuwstraat 40, B-9000 Gent, Belgium
[b] Ghent University, Department of Industrial Technologies and Construction, Research Group Construction and Structural Engineering & Surveying, Valentin Vaerwijckweg 1, B-9000 Gent, Belgium
[c] Ghent University, Department of Architecture and Urban Planning, Jozef Plateaustraat 22, B-9000 Gent, Belgium

HIGHLIGHTS

- Calcium silicate has an atypical drying behaviour.
- The second drying stage shows an intermediate platform in the temperature course.
- A detailed 3D drying model explains the drying behaviour.
- During drying, the dried out top acts as a thermal insulation layer.

ARTICLE INFO

Article history:
Received 18 September 2013
Received in revised form 9 April 2014
Accepted 26 April 2014
Available online 3 June 2014

Keywords:
HAM
Modelling
Drying
Experiment
Validation
Calcium silicate
Temperature
Moisture content
Finite volume

ABSTRACT

Nowadays, the hygrothermal performance of the building envelope is often evaluated using HAM (heat, air and moisture) models. These models can be used to predict the hygrothermal response of the building envelope and can assist in reducing the risk of any moisture-related damage (e.g. decrease of thermal insulation value due to wetting, interstitial condensation, etc.). At the same time it is important to understand the physical mechanisms of wetting and drying of building materials. Experimental research can contribute to a better understanding of these mechanisms.

In this paper the focus lies on the wetting and drying phenomena occurring in building materials. One specific material is highlighted: calcium silicate. Calcium silicate is an inorganic, hygroscopic and capillary active insulation material, which is often used in interior thermal insulations systems. The paper describes a drying experiment in which a calcium silicate sample dries out starting from saturation. The experiments showed that calcium silicate has an atypical drying behaviour: during the second drying phase an intermediate plateau was observed in the temperature course. Numerical simulations performed with a recently developed CFD–HAM model were compared with the experimental results and were used to explain the experimental observations.

1. Introduction

During the last decades, the requirements for buildings have increased tremendously: a comfortable indoor climate and a healthy environment are desired for the building occupants, in combination with a sustainable and energy efficient design and a low energy use.

Although the quality of building envelopes has grown during the last decades, moisture-related problems may still arise. Moisture-damage can be the result of rising damp, surface condensation (as a result of thermal bridges) or interstitial condensation (for instance caused by interior insulation systems). The presence of a high moisture content in building envelopes during service life should be avoided: an increased moisture content may lead to serious structural as well as to aesthetic problems: corrosion, loss of thermal insulation quality [1,2], mould and mildew [3], salt efflorescence [4,5], etc. Avoiding the risk of damage to the building envelope is related to the hygrothermal performance of building materials and building envelope systems. HAM (heat, air and moisture) models are widely used to predict heat and mass transfer in building envelope systems and allow building designers to evaluate the performance of the building and its envelope in advance or to suggest alternative solutions in case of deficiencies. The knowledge of the wetting and drying behaviour of building materials is an important aspect in this matter.

In the past a lot of research has been done on the drying and wetting kinetics of porous materials in general and on building

* Corresponding author. Tel.: +32 92643289; fax: +32 92643575.
E-mail address: marnix.vanbelleghem@UGent.be (M. Van Belleghem).

http://dx.doi.org/10.1016/j.conbuildmat.2014.04.129
0950-0618/

Nomenclature

C	specific heat capacity (J/kg K)
C_b	Stefan–Boltzmann constant (W/m^2 K^4)
D_{va}	diffusivity of water vapour into air (m^2/s)
E	total energy (J/m^3)
g	moisture flux (kg/m^2 s)
h	specific enthalpy (J/kg)
h	convective heat transfer coefficient (W/m^2 K)
h_m	convective mass transfer coefficient (s/m)
k	turbulent kinetic energy (J)
K_l	liquid permeability (s)
L	latent heat of evaporation (J/kg)
p_c	capillary pressure (Pa)
p_{sat}	saturation vapour pressure (Pa)
p_v	partial vapour pressure (Pa)
q	heat flux (W/m^2)
RH	relative humidity (–)
R_v	specific gas constant for water vapour (J/kg K)
t	time (s)
T	temperature (K)
w	moisture content (kg/m^3)
$\partial w/\partial p_c$	moisture capacity (kg/m^3 Pa)
$y+$	dimensionless distance to the wall (–)

Greek symbols

ε	emissivity (–)
λ	thermal conductivity (W/m K)
μ	water vapour resistance factor (–)
ρ	density (kg/m^3)
ψ_0	open porosity (–)
ω	specific dissipation rate of turbulent kinetic energy (1/s)

Subscripts

c	capillary
l	liquid
mat	material
rad	radiation
s	surface
sat	saturation
v	vapour

Acronyms

2D	2 dimensional
3D	3 dimensional
ACH	air changes per hour
Al	aluminium
CaSi	calcium silicate
CFD	computational fluid dynamics
CRP	constant drying rate period
FRP	falling drying rate period
HAM	heat, air and moisture transport model
PUR	polyurethane
SIMPLE	semi-implicit method for pressure linked equations
SST	shear stress transport

materials in particular. A wide range of textbooks can be found that describe the combined heat and moisture transport in porous materials [6,7]. Based on this knowledge several numerical models have been developed that help scientists and engineers to study and predict drying and wetting of porous (building) materials.

The past decade the drying behaviour of the most common building materials has been studied with numerical models. Most of these materials are hygroscopic and/or capillary active (wood [8], gypsum board [9], brick [10–12]). Insulation materials on the other hand are one class of building materials that is seldom addressed in drying studies. This is because most insulation materials (XPS, EPS, PUR, PIR, mineral wool, etc.) are non-hygroscopic and non-capillary active.

However some building materials with a fine pore structure combine a hygroscopic and capillary active behaviour with a low thermal conductivity. An example of such a material is calcium silicate.

Calcium silicate (Ca_2SiO_4) is an inorganic, hygroscopic and capillary active insulation material. It is composed of hydrous calcium silicate and reinforcing fibres. It is produced by autoclaving the slurry of lime and silica powder, adding some fibrous filler. The resulting mixture is formed into desired shapes [13]. Due to its resistance to high temperatures it is often used as high-temperature or fire resistant insulation. It is also often used as thermal insulation material in interior thermal insulation systems without water vapour barrier, e.g. in historic buildings where the original façade must be kept in its original appearance [14].

The high moisture buffering capacity of the material enables it to dampen humidity variations and occasional interstitial condensation can be redistributed and transported out of the material due to the high capillary activity [15]. The material has a higher capillary moisture content than for example brick. The pore volume distribution of calcium silicate is characterised by a broad pore system including a significant fraction of fine pores in the hygroscopic region and a coarse pore system in the capillary region [16]. The pore size varies from several nanometers up to a millimeter [13].

Researchers have already been working on the characteristics of the calcium silicate material. For example Hamilton and Hall have studied its chemical and mineralogical composition [17]. The relationships between thermal conductivity and microstructural parameters, such as porosity and pore size were experimentally studied by Do et al. for two calcium silicate boards of different densities [18]. Mar et al. developed a theoretical model for the thermal conductivity and apparent thermal conductivity of calcium silicate for a wide range of temperature and moisture conditions [13].

The hygric properties of calcium silicate (capillary moisture uptake, absorption coefficient, isothermal adsorption and desorption curves, water vapour resistance factor), have been extensively measured by six laboratories in the frame of the HAMSTAD project [19]. More recently, Pavlík et al. measured moisture profiles in desorption in a calcium silicate sample using time domain reflectometry. The results were used as input data for determining the moisture diffusivity of the material during drying [14]. Pease et al. used X-ray attenuation measurements to monitor the moisture content of building materials, amongst others calcium silicate [20]. The influence of the relative humidity on the diffusion process of VOC's in porous materials was studied by Xu and Zhang [21].

Due to its hygroscopic and capillary characteristics, calcium silicate is also often used in heat and mass transfer experiments to validate HAM models. In the past, it has been used to validate a coupled CFD–HAM model and a coupled BES–HAM model [22–25].

In this paper however the drying behaviour of calcium silicate when initially saturated with water is studied. Due to the combination of a high capillary activity and low thermal conductivity when