

HYGROSCOPICITY OF CARBONATED CALCIUM SILICATE INSULATION BOARDS

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Abstract:

In the monitored calcium silicate insulation boards microstructures changes due to carbonation were noticed. These changes resulted in changed sorption curves, which could influence resultant thermal conductivity in the range of relative humidities, common in building envelopes. The hygroscopicity changes were of different importance for the particular types of calcium silicate insulation boards. Therefore the influence of the particular material composition on the microstructure and consequently on hygroscopicity changes was investigated.

Keywords:

Carbonation, microstructure, hygroscopicity, specific surface area

INTRODUCTION

The performance of thermal-insulation building materials results from the complex of several phenomena. It involves not only the dependence of thermal conductivity on moisture content but also the material ability to transport and accumulate moisture. The ability of the moisture transport and accumulation of capillary-porous materials depend on their pore structure. The pore structure can be changed by the influence of aggressive gaseous media during their exploitation. In the paper the pore structure and consequent hygroscopicity changes due to carbonation process were investigated for six types of calcium silicate boards.

Calcium silicate (CS) is an inorganic high porous fibre-reinforced thermal insulation material composed of the hydrous calcium silicate and the cellulose reinforcing fibres. Some types of CS have been developed as thermal insulation materials applicable from the indoor side of envelope parts of buildings.

EXPERIMENTAL

The pore structure parameters and parameters of water vapour transport and accumulation were determined for six types of CS. Before the tests, the samples were sheltered by PE foils in order to avoid possible influence of air carbon dioxide, but partial carbonation of the original samples could not be avoided. After finishing the tests the specimens were exposed to the accelerated carbonation process in the chamber with 17% concentration of carbon dioxide until the ultimate carbonation has been reached. Then the same pore structure and material parameters as in the case of original samples were determined for the ultimately carbonated ones. The composition of the original and carbonated CS samples were done by X-ray diffraction analysis (RTG) and differential thermal analysis (DTA).

The pore size distribution, the open porosity and the specific surface area of pores were studied using the mercury intrusion porosimetry (MIP): the high-pressure porosimeter mod. 2000

and macro-porosimeter mod. 120 (both Carlo Erba, Milan). This system enables determination of micropores with the radius from 3.7 up to 7500 nm and of larger pores with a radius up to 0.06mm. The porosimetry measurement was carried out by the fraction of broken dried (up to 105°C) samples. Specific surface area of pores was determined using the cylindrical model. The open porosity was also determined from the suction test.

The adsorption moisture contents were determined after storing the specimens in climatic chambers with relative humidities of 30% and 78% and temperature 19°C. The water vapour permeability was measured by the standard dry-cup (0 – 60% RH) and wet-cup (100 – 60% RH) methods.

RESULTS AND DISCUSSION

According the results of the RTG analysis the tested CS materials contained only one phase of the calcium silicate hydrates – xonotlit, with the exception of the CS B, which contained a composition of tobermorit and xonotlit [2].

The changes of pore size distribution, the bulk density, open porosity and pore radius median caused by carbonation are shown in Tab. 1 and 2 [1]. The pore size distribution changes were not substantial, but in all tested samples the similar trend could be noticed – a decrease of the portion of large pores (with the radii greater than 10^3 nm) and an increase of the small pores portion (in most cases with the radii below 10^2 nm). This trend is different from the pore structures changes in hardened cement paste or plasters with cement binder, where the reduction of the portion of small pores is typical result of carbonation [4], [5].

The bulk density has increased in all tested CS samples. The changes in pore size distribution resulted in the changes of pore radius median and specific surface area of pores. The microstructure changes were different depending on the type of CS. The pore radius median changes were not significant, but the specific surface of the pores has increased significantly in case of CS 250, CS A and CS B.

Table 1. The pore size distribution of the original and ultimately carbonated (carb) CS samples (MIP) [1]

CS	< 10 nm	10 - 10^2 nm	10^2 - 10^3 nm	10^3 - 10^4 nm	> 10^4 nm
1100	0	4	91	4	3
1100 carb	0	4	90	3	2
1100M	0	3	89	6	0
1100M carb	0	3	93	2	1
200	0	11	74	6	11
200 carb	0	16	78	5	3
250	0	9	86	2	1
250 carb	2	10	85	0	1
A	0	5	88	6	2
A carb	4	3	84	3	5
B	1	9	81	6	3
B carb	4	6	79	5	5

Table 2. The pore structure parameters of the original and ultimately carbonated CS samples obtained from MIP [1] and suction test.

Calcium silicate	Original				Ultimately carbonated			
	BD	OP	M_{TP}	SSA	BD	OP	M_{TP}	SSA
	kg/m ³	(suction) %	nm	(MIP) m ² /g	kg/m ³	(suction) %	nm	(MIP) m ² /g
CS 1100	239	91.0	471	23.36	263	91.0	463	23.14
CS 1100M	239.5	91.0	423	26.38	268	91.0	423	24.98
CS 200	207	93.0	244	46.89	222	93.0	231	59.41
CS 250	289	90.0	287	39.11	314	90.0	275	62.04
CS A	245	91.0	433	21.41	293	91.0	441	66.86
CS B	225	93.0	364	58.45	263	93.0	418	79.94

BD – bulk density, OP – open porosity, M_{TP} – pore radius median, SSA – specific surface area of pores.

Table 3. The water vapour accumulation and transport parameters of the original and ultimately carbonated CS samples

Calcium silicate	Original				Ultimately carbonated			
	W_{30}	W_{78}	μ_{dc}	μ_{wc}	W_{30}	W_{78}	μ_{dc}	μ_{wc}
	kg/m ³	kg/m ³	-	-	kg/m ³	kg/m ³	-	-
CS 1100	3.6	4.8	5.1	2.0	5.6	9.3	4.5	2.0
CS 1100M	3.8	5.6	5.1	1.9	6.0	9.5	4.5	2.0
CS 200	3.8	9.3	5.1	1.9	3.2	8.2	4.4	1.8
CS 250	6.0	11.1	5.1	1.9	6.6	11.3	4.4	2.0
CS A	2.0	5.0	3.6	1.8	6.8	13.9	4.6	1.8
CS B	4.0	10.0	4.4	2.3	7.0	14.5	4.9	2.1

W_{30} , W_{78} – sorption moisture contents at 30 and 78% RH respectively, μ_{dc} , μ_{wc} water vapour resistance factors determined by dry cup and wet cup respectively

Table 4. The MIP specific surface areas (SSA_{Hg}), BET specific surface areas (SSA_{H_2O}) and statistical thickness h of adsorbed water film at 30% and 78 % RH of the original and ultimately carbonated CS samples

Calcium silicate	Original				Ultimately carbonated			
	SSA_{Hg}	SSA_{H_2O}	h [nm]		SSA_{Hg}	SSA_{H_2O}	h [nm]	
	m ² /g	m ² /g	30 %	78 %	m ² /g	m ² /g ³	30 %	78 %
CS 1100	23.36	60.97	0.25	0.64	23.14	86.18	0.25	0.63
CS 1100M	26.38	55.68	0.25	0.46	24.98	90.62	0.22	0.38
CS 200	46.89	74.30	0.25	0.33	59.41	58.34	0.25	0.41
CS 250	39.11	84.03	0.27	0.42	62.04	94.13	0.25	0.39
CS A	21.41	33.04	0.25	0.62	66.86	93.94	0.25	0.51
CS B	58.45	71.96	0.25	0.62	79.94	107.73	0.25	0.51

In Tab. 3 the changes of the water vapour accumulation and transport parameters - sorption moisture contents at 30% and 78% RH and water vapour resistance factors – caused by carbonation are presented. The water vapour permeability values were not changed by carbonation. The result could be expected - the water vapour permeability measured by the dry cup depends on the total connected pore volume and its tortuosity. Due to no changes of open porosity also the water vapour permeability values remained unchanged. On the other hand the sorption moisture contents

Table 5. The amount of calcium carbonate in the original and the ultimately carbonated CS samples [2]

Calcium silicate	Original	Ultimately carbonated
	CaCO ₃ %	CaCO ₃ %
CS 1100	1.84	30.09
CS 1100M	1.82	28.03
CS 200	-	11.36
CS 250	1.61	18.87

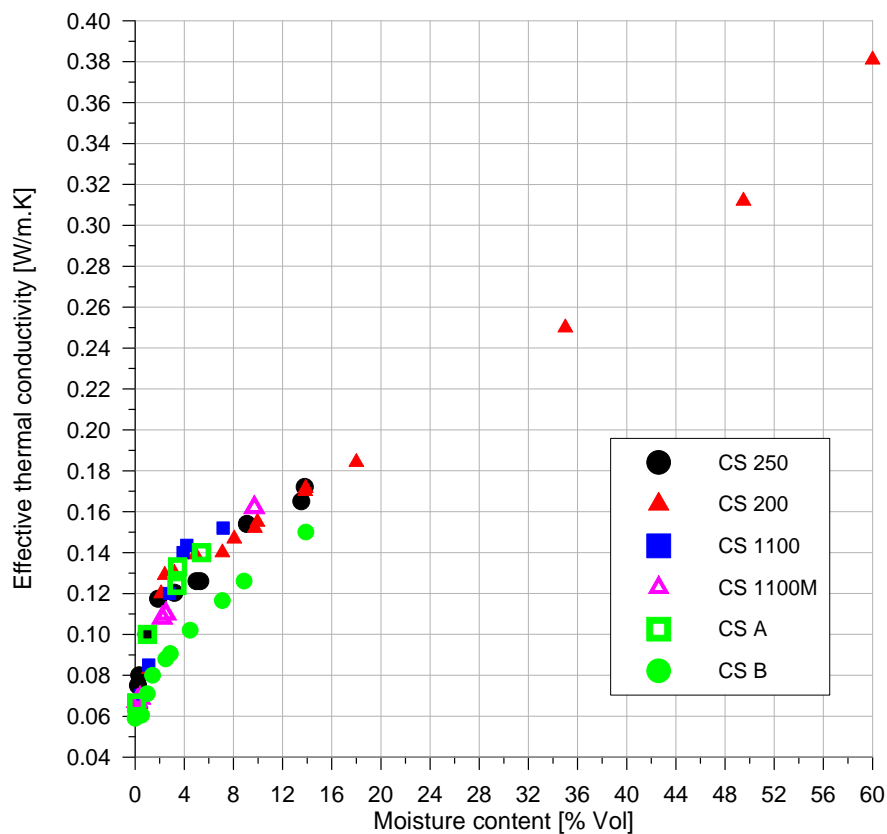


Fig. 1 The measured effective thermal conductivity moisture dependences of CS samples [6]

remained practically unchanged only in case of CS 200 and CS 250. In case of the other four CS materials the higher sorption moisture contents have been determined for ultimately carbonated CS samples.

The BET SSA was calculated from the water vapour sorption data for 15 and 30% RH, using the formula (1), valid in case of H₂O molecules hexagonal arrangement [3]:

$$SSA_{H_2O} = m_m \cdot 3.5 \cdot 10^3 \text{ [m}^2/\text{g]} \tag{1}$$

where m_m is the amount of mono-layer adsorbate [kg /kg]

The calculated BET SSA values compared with the ones obtained from MIP are reported in Tab. 4. The most significant SSA increase has been noticed for CS A and CS B samples. In case of these samples the trends in SSA increase were similar for BET and MIP method. In case of the other CS materials the BET SSA of the ultimately carbonated samples has increased or remained unchanged. On the base of the measured sorption moisture contents and the calculated BET SSA

values the statistical thickness of the adsorbed water film has been determined according to following relation:

$$h = u_v / SSA_{H_2O, v} \quad (2)$$

where u_v is the volumetric moisture content [m^3/m^3] and $SSA_{H_2O, v}$ is the BET specific surface area in m^2/m^3 .

The calculated statistical thicknesses of the adsorbed water film correspond roughly to the values presented for xonotlit by Tada: $h = 0.27$ nm for 30% RH and $h = 0.6$ nm for 78% RH [7].

With the aim to explain the different results achieved for the particular CS types and to evaluate an effect of possible different degree of carbonation of the original samples the amount of the calcium carbonate in the original and ultimately carbonated samples were determined by DTA (Tab. 5). The results of DTA have showed that the amount of calcium carbonate in original samples

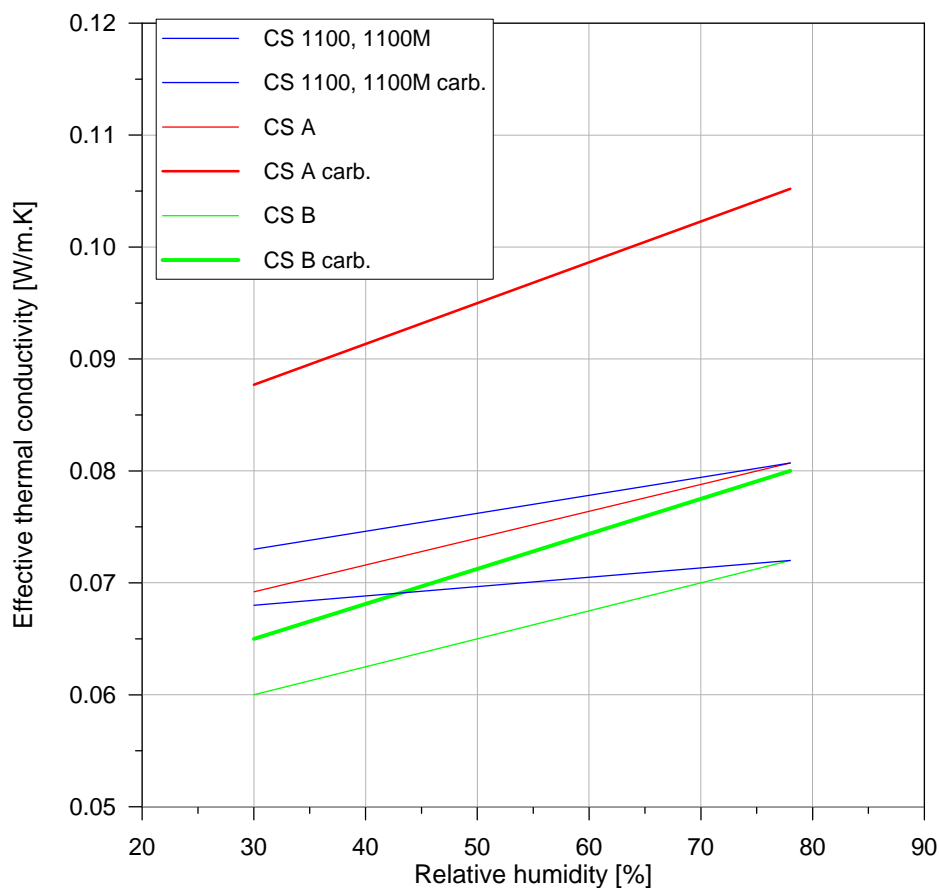


Fig. 2 The practical values of CS thermal conductivity calculated using the measured sorption moisture contents and effective thermal conductivity moisture dependences

was negligible. On the other hand it confirmed the differences in carbonation process among the particular CS materials (resulting in different amounts of calcium carbonate in ultimately carbonated samples) but the reason of the differences was not found out.

From the point of view of CS application in the envelope parts of buildings the dependence of the thermal conductivity on the moisture content is of great importance. The thermal conductivity dependence on moisture content of the tested CS materials was in detail analysed elsewhere [5] and the measured results are presented in Fig. 1. The carbonation has not changed the dependency of the

thermal conductivity on the moisture content, but the higher moisture accumulation ability could caused the higher values of effective thermal conductivity in the range of relative humidities common in building envelope parts as it is presented in Fig. 2. From the tested set of CS boards, the highest increase of the practical value of effective thermal conductivity can be expected in case of CS A (up to 30% in the range 30 – 80% RH).

CONCLUSIONS

The microstructure changes due to carbonation and their influence on the water vapour accumulation and transport were investigated for some calcium silicate thermal insulation materials.

The carbonation has caused an increase of the portion of the small pores resulting in an increase of MIP SSA in the most of the tested CS samples. Changes in pore size distribution resulted in changed sorption curve of the CS materials – in four of the six tested materials the moisture accumulation capacity has increased. The changes of hygroscopicity were different for particular types of tested CS boards in spite of their very similar composition.

The changes of the water vapour transport parameters caused by carbonation were practically negligible.

Changes in sorption curve have influenced the values of effective thermal conductivity of some of the tested CS materials in the range of relative humidities common in building envelope parts. From the tested set of CS boards, the highest increase of the practical value of effective thermal conductivity can be expected in case of CS A (up to 30% in the range 30 – 80% RH). Therefore in long-term hygro-thermal performance prediction the material parameters of the ultimately carbonated CS materials should be taken into account.

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