

# Thermal and moisture properties of calcium silicate insulation boards

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**Abstract.** The purpose of this research was to determine thermal and moisture properties of calcium silicate insulation boards available on the Finnish market. Ruggedness testing and test arrangement development were done related to the pressure plate test, which was used to measure desorption isotherms in capillary range. Four calcium silicate and one calcium hydroxide board were examined. The determined material properties are water vapour permeability, water absorption coefficient, capillary saturation water content, moisture sorption isotherm in hygroscopic and capillary range, thermal conductivity and specific heat capacity. Ruggedness tests and development were done to the pressure plate measurement method. Capacitance needles were tested as a method to evaluate the state of equilibrium and different vacuum saturation methods were tested.

## 1 Introduction

Retrofitting of insulation to existing structures is becoming more popular as energy consumption of buildings is under interest. Calcium silicate boards are known to have a low thermal conductivity as well as a capillary active pore structure [1]. Therefore, they can be used as internal insulation of old buildings [2]. The use of HAM-models is an effective tool to analyse the functioning of a renovated structure in advance, but the reliability of calculation results is highly dependent on material properties input [3]. The aim of this study was to determine the most important building physical material properties of calcium silicate boards available on the Finnish market, but anomalies in test results made it necessary to incorporate ruggedness testing and to develop the pressure plate test method.

The differences between equilibrium levels achieved by capillary saturation and vacuum saturation [4] indicate that contrary to standards the specimen should be saturated between pressure levels. Consequently, the length of saturation is to be shortened. Accordingly, the length of evacuation and the time specimens were kept under water were varied though the repeatability of vacuum saturation has been proved [5]. As there were unexpectedly long equilibration times compared to the ones used for example in [5], a capacitance needle method presented in several experimental arrangements [1] [6] was piloted to observe the

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moisture content change of specimens during pressurization in order to confirm that equilibrium moisture content was achieved.

2 Materials and methods

2.1 Material characterization

Four calcium silicate (CaSi) and one calcium hydroxide board (Ca(OH)<sub>2</sub>) were examined. The boards represent products that were available on the Finnish market. The brand name, material, thickness and dry density of the boards are listed in Table 1.

Table 1. Insulation boards investigated.

Brand name	Material	Thickness [mm]	Dry density [kg/m³]
Kasil E	CaSi	25	300
Promasil 1000	CaSi	25	245
Epatherm	CaSi	30	230
Skamotec 225	CaSi	50	225
Kasil Pura	Ca(OH) <sub>2</sub>	50	130

The boards were received from manufacturers and distributors. The differing Kasil Pura was included in the study as it is promoted as a substitutive low-cost alternative for the Kasil E board.

The determined material properties were water vapour permeability, water absorption coefficient, capillary saturation water content, moisture sorption isotherm in hygroscopic and capillary range, thermal conductivity and specific heat capacity. In general, standard methods were used, but minor developments were piloted in the arrangements of measuring the capillary sorption isotherm. The measuring methods and associated standards are presented in Table 2.

Table 2. Test methods and used specimen sizes.

Material property	Test Method	Standard	Specimen Size
Water vapour permeability	Wet cup with RH 93 % and RH 51 %	EN-ISO 12572 (2001)	diameter 185 mm
Water absorption coefficient	Automated free water intake measurement	EN ISO 15148 (2002)	diameter 185 mm
Capillary saturation	Automated free water intake measurement	NT build 368 (1991)	diameter 185 mm
Sorption isotherm, hygroscopic	Conditioning at RH 33, 55, 75, 85, 93, and 97 %	EN ISO 12571 (2014)	diameter 140 mm
Sorption isotherm, capillary	Pressure plate measurement	NT Build 481 (1997) ASTM C1699-09 (2015)	diameter 57 mm
Thermal conductivity	Heat flow meter	EN 12667 (2001)	300x300 mm²

Specific heat capacity	Heat flow meter	ASTM C1784-13:2014	300x300 mm <sup>2</sup>
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The thickness of the specimens was the same as the original board thickness in all tests except the pressure plate measurement where thickness was approximately 10 mm.

## 2.2 Ruggedness tests and developments

The pressure plate measurement test used to measure the capillary sorption isotherm can be divided to three parts: 1. Vacuum saturation of specimens, 2. Pressurization of specimens in a pressure plate chamber until equilibrium moisture content is achieved, and 3. Moving the specimen to next pressurization level. Developments were done in each part.

The saturation of specimens was done in a vacuum chamber, in which the absolute pressure was under 0,05 mbar. Ruggedness tests were done to see how different variables affect the moisture content achieved by vacuum saturation. The tests were done with Skamotec 225 and Kasil Pura. Twelve oven-dried specimens of both materials were placed inside the vacuum chamber and evacuated for a length of time. After air was evacuated from the chamber, it was filled with water and specimens were left immersed for a specified length of time. After this the specimens were weighed to determine the saturation moisture contents of the materials.

According to the standard method, the equilibration of the specimen during pressurization is observed by measuring the amount of water that flows out from the pressure chamber. The outflow amount is to be measured with a burette, but in order to get more information, a more direct method to estimate the change in moisture content was tested. This was done by measuring capacitance between two parallel metal rods inserted into holes that were drilled in one or two specimens of each material. The rods were 1,6 mm in diameter, 60 mm in length and were placed 10 mm apart. The rods were connected to a capacitance meter outside the chamber by wires and a lead-trough in the chamber wall. As moisture content affects the permittivity of porous materials, it can be evaluated by measuring the material's capacitance.

In the third part of the test the equilibrated specimens are moved to the next pressure level. As pressure level rises, the expected equilibrium moisture content is to be lower. As there were anomalies in the results, a method where specimens were vacuum saturated between every pressure level was adopted.

## 3 Results

### 3.1 Material properties

The material properties of examined calcium silicate boards and one calcium hydroxide board are shown in Tables 3, 4 and 5.

**Table 3.** Measured material properties of examined insulation boards.

Material	h [mm]	$\rho_{dry}$ [kg/m <sup>3</sup> ]	$\delta_v$ [ $1 \cdot 10^{-6}$ m <sup>2</sup> /s]	$A_w$ [kg/m <sup>2</sup> s <sup>0.5</sup> ]	$w_{cap}$ [kg/m <sup>3</sup> ]	$\lambda$ [W/mK]	$c_p$ [J/kgK]
Kasil E	25	253	8,14	1,182	832	0,076	860
Promasil 1000	25	232	7,98	1,199	839	0,071	790

Epatherm	30	236	9,32	1,288	837	0,070	830
Skamotec 225	50	227	10,8	0,643	700	0,072	820
Kasil Pura	50	133	11,7	0,137	347	0,053	910

The dry mass was measured by 100 x 100 mm<sup>2</sup> specimens with original material thickness after oven drying in +105 °C to constant weight.

The sorption isotherm in hygroscopic range is summarized in table 4.

**Table 4.** Sorption isotherm in hygroscopic range of examined insulation boards. Moisture contents are expressed as mass of evaporable water per volume, w [kg/m<sup>3</sup>].

RH %	Adsorption						Desorption				
Material	33	57	75	85	93	97	93	85	75	57	33
Kasil E	3,2	4,1	5,3	6,5	10,7	34,1	18,5	14,6	13,4	12,0	11,2
Promasil 1000	3,2	4,1	5,5	7,1	12,7	36,2	20,8	16,7	15,4	14,1	13,2
Epatherm	3,5	4,2	5,2	6,3	10,1	26,4	16,5	13,6	12,6	11,5	10,9
Skamotec 225	2,7	3,8	5,8	8,2	15,0	38,5	23,3	16,5	14,9	13,3	12,3
Kasil Pura	4,0	4,8	6,2	8,0	14,6	32,3	21,9	12,4	10,8	9,8	8,8

As there were anomalies in the sorption isotherms measured in capillary range, table 5 is not complete. Unverified results are displayed with a grey background, although all data is to be verified.

**Table 5.** Sorption isotherm in capillary range of examined insulation boards. Unverified results are shown with a grey background colour. Moisture contents are expressed as mass of evaporable water per volume, w [kg/m<sup>3</sup>].

	RH%	99,977	99,927	99,77	99,27	97,7	92,7
Material	bar	0,316	1	3,16	10	31,6	100
Kasil E		807	763	715	435	367	165
Promasil 1000		814	782	734	453	213	440
Epatherm		829	782	732	716	294	18,5
Skamotec 225		857	827	817	789	646	488
Kasil Pura		114	97	94	82	301	178

The verified results of pressure plate measurements were produced after developments were made. The biggest source of error turned out to be the loss of capillary contact during the weighing between pressure levels which was later avoided by repeating the vacuum saturation step prior to each pressurization. Pressure plate tests that were repeated a second time (pressure levels 0,316; 10 and 100 bar) revealed that equilibrium was not fully achieved during the first measurements, as there was a noticeable drop in moisture contents in the 10 and 100 bar tests.

**3.2 Ruggedness tests and developments**

The evacuation and immersion times in different rounds of ruggedness tests are summarized with the results in table 6. The results are presented as gravimetric water content  $u_{vac}$  [kg/kg] and moisture content  $w_{vac}$  [kg/m<sup>3</sup>]. The gravimetric water content is calculated from the water content after saturation and the last dry weight before evacuation,

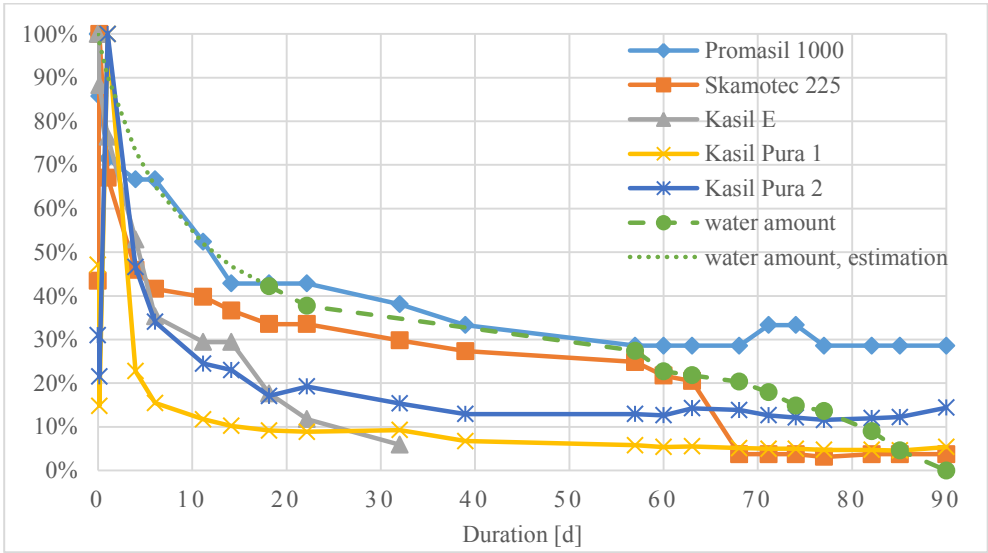
whereas the moisture content is calculated from the water content after saturation and the volume of the specimen measured in the beginning of the ruggedness tests. This makes a small difference to the results of Kasil Pura, because its mechanical strength is very low, and the specimens therefore suffered from abrasion during multiple saturation cycles.

**Table 6.** Definition of the ruggedness test variations and the results of the vacuum saturation tests.

Nr.	Evacuation time	Immersion time	Skamotec 225		Kasil Pura	
			$u_{vac}$ [kg/kg]	$w_{vac}$ [kg/m <sup>3</sup> ]	$u_{vac}$ [kg/kg]	$w_{vac}$ [kg/m <sup>3</sup> ]
1	3 h	3 d	3,94	896	6,17	767
2	3 h	1 h	4,01	897	6,23	751
3	1 d	3 d	4,01	896	6,19	733
4	1 wk	3 d	4,03	895	6,34	728
5	1 d	1 wk	4,05	895	6,39	718
6	1 d	1 wk	4,07	893	6,40	698
7	5 d	3 d	4,06	891	6,13	669
8	1 d	1 wk	4,06	890	6,37	656
9	1 d	3 d	4,08	890	6,32	628
10	1 d	1 wk	4,10	889	6,20	584

From Table 6 it can be deduced how the evacuation and immersion time did not make a great difference to the vacuum saturation water content and the fastest method can be used when saturating specimens between pressure levels. The changes in the results of Kasil Pura are mostly due to abrasion of the specimens' surface.

The capacitance measurements are presented in Figure 1 as a percentage value of the maximum capacitance measured from the specimen. The actual measured capacitance values (Fig. 1.) were 21...0,1 nF. The water outflow is also presented. The results indicate that capacitance measurement can be used to estimate the state of the equilibrium of the specimen.



**Fig. 1.** The results of capacitance and water outflow measurements during 10 bar pressure plate measurement.

In order to compare it with the capacitance measurement results, the water amount is estimated by the measured outflow rate assuming it is zero in the end of the graph. The maximum amount of water is calculated assuming cumulative outflow rate as the outflow amount in the beginning was not measured precisely.

The water content of ceramic pressure plates may affect the results as the capacitance change does not follow the outflow amount through the whole experiment. The results are though comparable and similarity between outflow and capacitance is even better in 100 bar experiment where there is no porous plate under the specimens.

The effect of development of the 3rd part of the pressure plate measurement can be seen in table 5, where the grey, unverified, values seem to be higher in the higher pressure levels compared to the verified ones. As the outflow of water had reduced quickly, it was assumed and later proved that capillary contact was lost because of evaporation from the specimens' surface during the weighing between pressurization levels and consequently equilibrium was not achieved.

#### 4 Discussion

The material properties of calcium silicate insulation boards available on the Finnish market are determined. The material properties are determined by standard method but because of anomalies in the pressure plate measurement results, ruggedness tests and method development were included in the research. While the measured properties correspond well to ones given by material manufacturers and distributors, there is still a need to determine the ones that are unknown as an input to HAM-models.

The investigated calcium silicate boards were mainly similar, but Skamotec 225 had some differing values especially related to capillary properties. As expected, Kasil Pura was a comparable product as an insulation material, but it does not have such a special capillary active pore structure as the calcium silicate insulation boards do. The measured properties also prove, that despite being mostly similar, some of the studied materials fare better in

terms of moisture transfer which should be taken into account in structures where high capillary activity is needed.

The ruggedness tests show, that with the investigated insulation boards the fastest method of vacuum saturating can be used. A quick saturation method is also good for the overall duration of the experiment, as it is necessary to saturate the specimens between pressurization levels to get more reliable results. The preliminary tests of capacitance needles show that they can be utilized to see how the moisture content of specimens is changing inside a closed pressure chamber.

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