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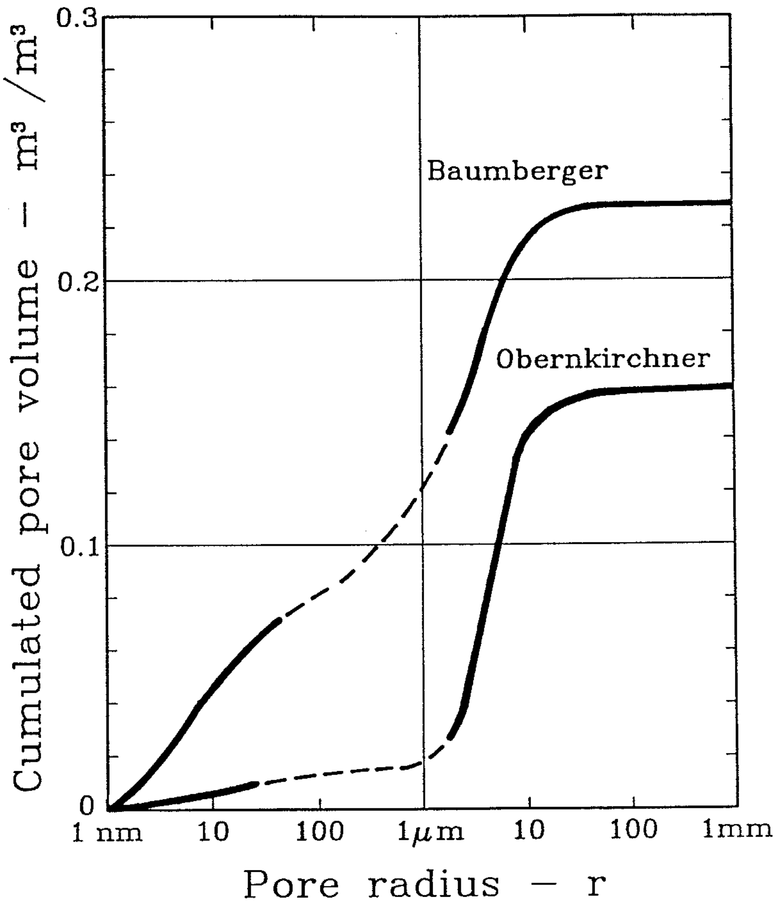

EXAMINATION OF TWO TYPES OF GERMAN SANDSTONE

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Examination of Two Types of
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The two types of German Sandstone examined in the present report are part of the materials included in the SCIENCE project "Characterisation of microstructure as a tool for prediction of moisture transfer in porous materials." No. SC1*-CT91-0737.

Key words

Sandstone, microstructure, moisture, strength, durability

Summary

The report summarizes an examination of two types of German Sandstone carried out as a students course work, spring 1992. The two types are Obernkirchner and Baumberger sandstone. Density, porosity, moisture sorption, pore size distribution, capillary suction, sound velocity, strength and sulfate resistance are measured.

CONTENTS

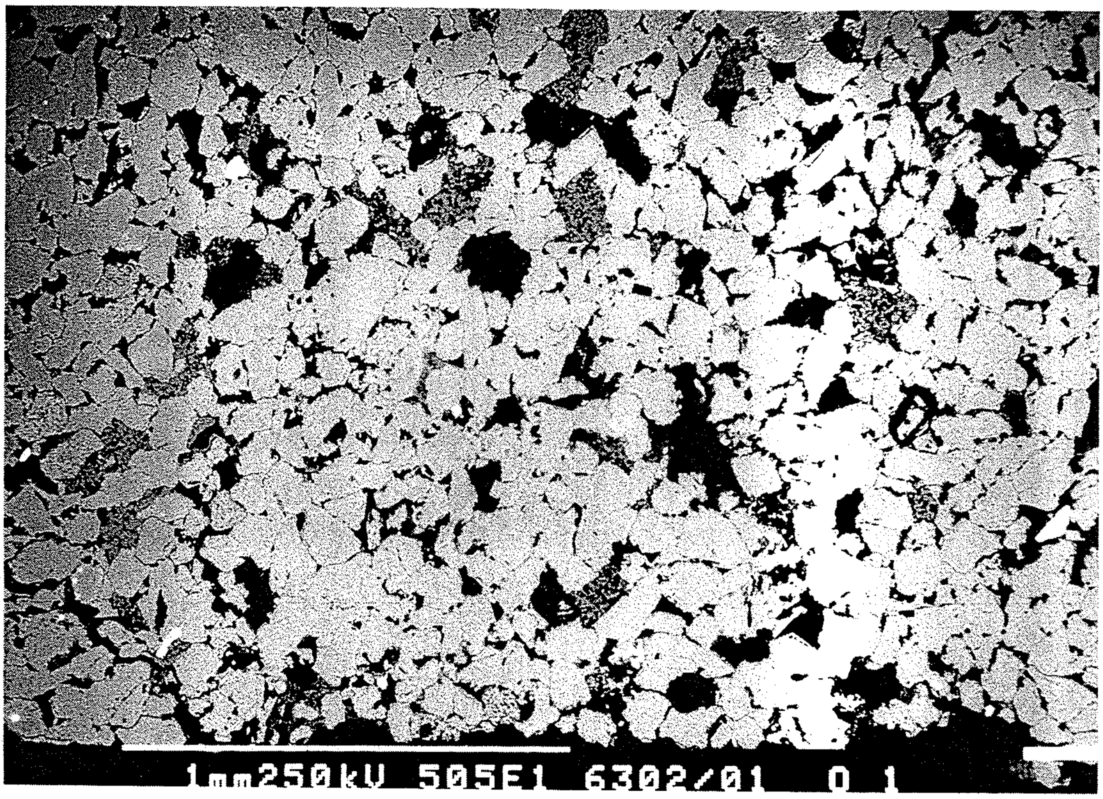
Introduction

The decay of natural stones has great interest among people working with the conservation of historic building and monuments. Experience with the strength and decay properties of the different kind of stones is necessary in the restauration activities and of course also in connection with construction of new buildings.

The study of the decay of natural stones and clay bricks has for some years been on the program of our laboratory as part of our work on the structure and properties of porous building materials in common. Especially the salt decay has been examined /2/. We have found, as many other examinators, that certain types of sandstones are expecially suffering from decay.

Our laboratory is participant of a SCIENCE program of The European Community named "Characterisation of microstructure as a tool for prediction of moisture transfer in porous materials". In this programme we have connections to the division in Holzkirchen of the German institute Frauenhofer-Institut für Bauphysik (IBP). This laboratory has made massive research on the field of decay of natural stones.

From IBP we have received two types of German sandstones for examination. To have the basic properties described, specimens of the two sandstones were given to three of our senior students, who made the examinations as part of a course work. The present report summarizes their results /1/.



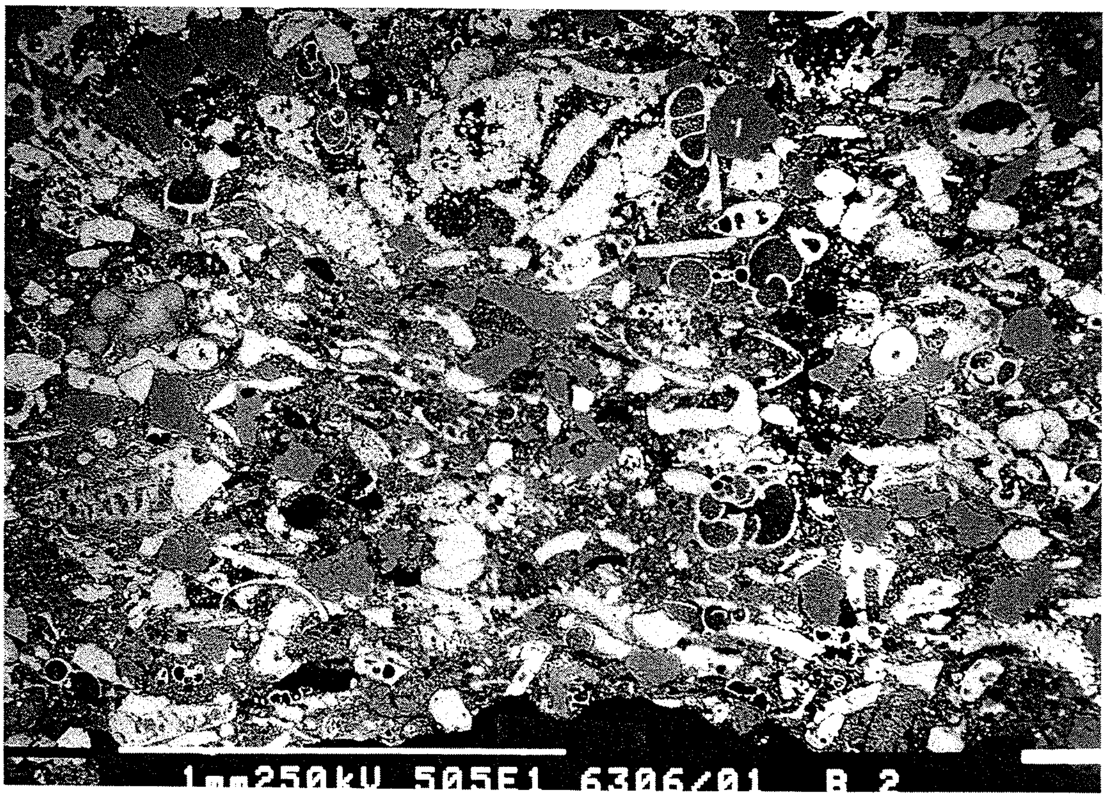


Figure 1. Microstructure of the Obernkirchner (top) and the Baumberger sandstone (bottom). Planar sections in SEM with back-scatter. Black areas are pores.

Procedure

The two stones to be examined are Obernkirchner sandstone and Baumberger sandstone.

Obernkirchner sandstone is mostly quartz bound. It has the reputation as a strong and durabel stone, highly weather resistant.

The second stone, Baumberger sandstone, is lime bound and known to have average durability.

IBP has measured properties of the two stones /3/, shown for comparison in Table 1.

In the following the two stones are abbreviated O and B respectively. Two specimens of each are used, named 1 and 2. The results are shown in Table 1.

The procedure in the examination was the following.

Two prisms of each type were chosen at random among the delivered number of test prisms. The dimensions, approximately 36 x 51 x 150 mm, were measured precisely.

Capillary suction was measured according to the standard method no. 1 and no. 2 of our laboratory. This standard includes a final vacuum saturation of the specimens to determine the open porosity /4/.

After drying and reconditioning to laboratory climate the sound velocity was measured using our "Pundit" apparatus.

Three point bending tests were carried out on the 20 ton M & F-testing machine at the Engineering Academy of Denmark in Lyngby. Immediately after the bending test, compression test was carried out on one of the halves of each of the prisms as modified cube test.

The other half of two of the prisms was tested for sulfate resistance according to DIN 52111.

The crushed material from the two compression test of each type was mixed and used to determine the adsorption and desorption isotherms. Pieces were chosen to structural examinations: Thin sections were examined in optical microscope, and planar sections in optical microscopy and in SEM with back scatter. Fractured surfaces were studied in SEM with secondary electrons. In the SEM the chemical composition was determined in EDAX.

A tiny part of the crushed materials was exposed to dilution in HCl.

In the following the results are presented. The structural properties are treated firstly and afterwards the physical properties.

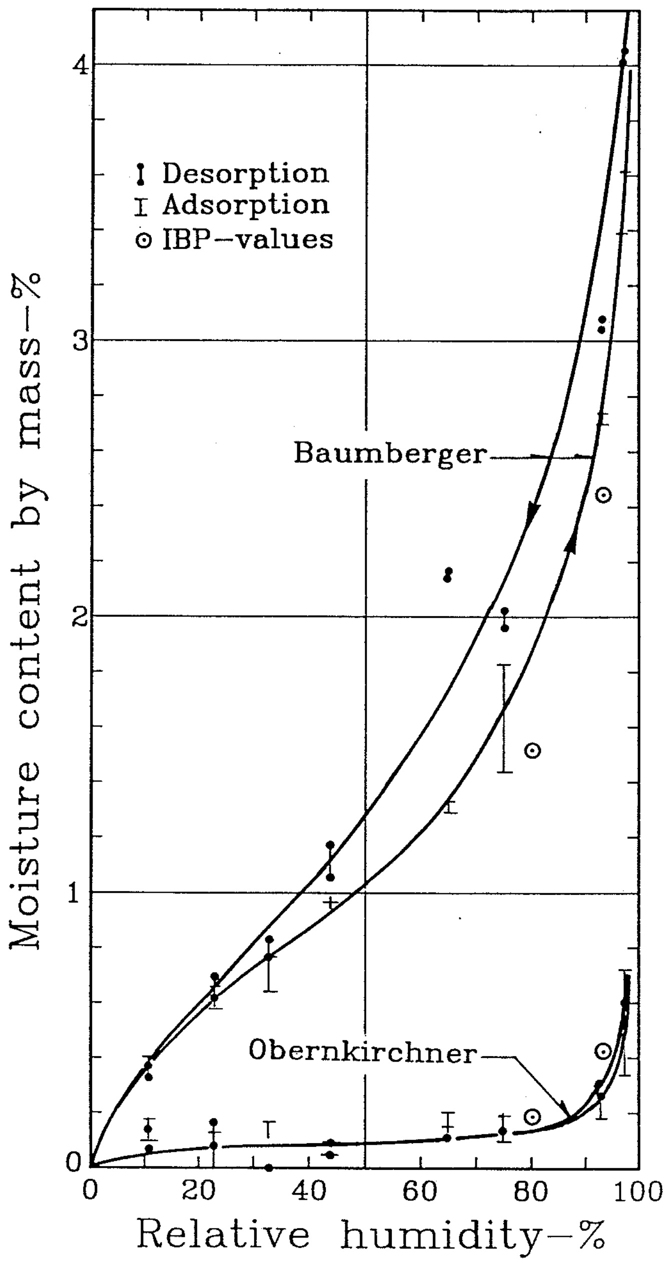


Figure 2. Sorption isotherms

Structure

The density and porosity values are collected in Table 1.

The density of the solid phase are determined from the vacuum saturation measurements i.e. that closed pores influences the results. This may declare why our results are lower than the ones from IBP.

Micrographs from the Scanning Electron Examinations are shown in Figure 1. It is seen that in O the difference between small and course pores is remarkable, whereas B has much smaller pores of equal magnitude. The pore structure in O draws the structure of air entrained concrete in mind.

The chemical compositions are shown in Table 2. (Oxygen and carbon can not be detected in EDAX). The information that O is quarts bonded and B is lime bounded is confirmed.

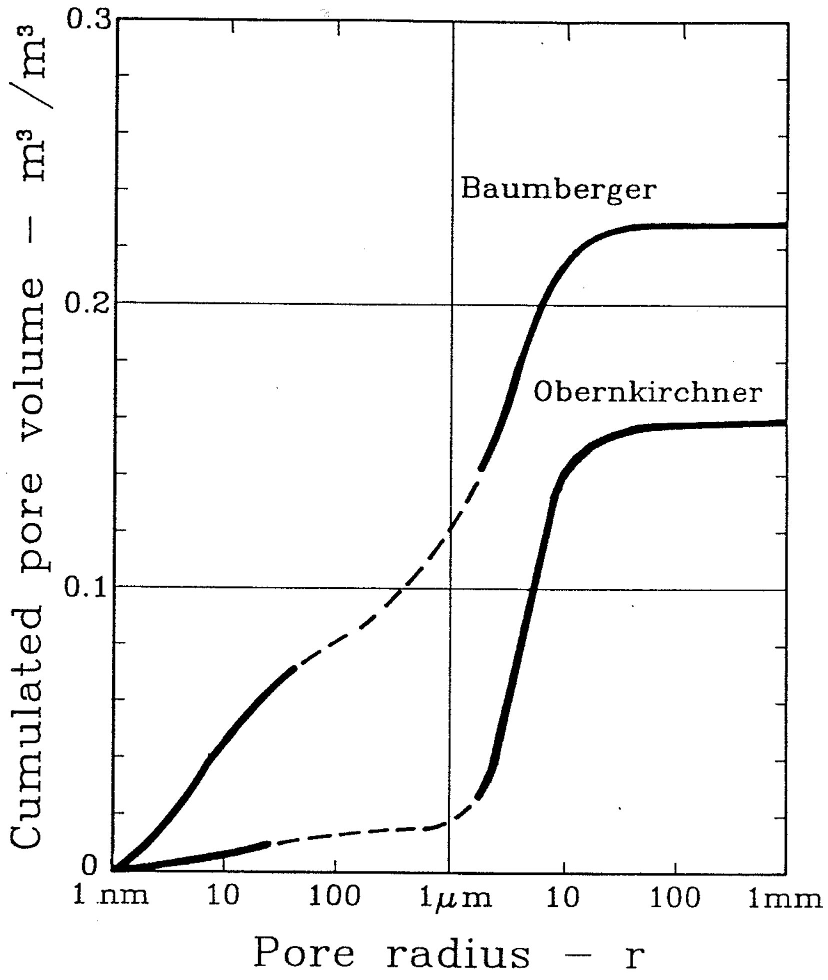


Figure 3. Pore size distribution. Above 2 m measured with optical microscope and SEM. Below 40 nm evaluated from water adsorption data. The "doudiness" of the curves is an expression of the incertenty in the methods.

Sorptions isotherms are shown in Figure 2.

It should be noticed that the sorption of the O-stone is so low, that the measurements are influenced by the accuracy of our weighing equipment. For this stone it is not possible to distinguish between ad- and desorption values.

Figure 3 shows the formal pore size distribution curves for the two materials. The formalism in the drawing of a pore size distribution curve is that the pores are assumed to be cylindrical, which they are not. The top horizontal part of the curve corresponds to the open porosity of the material. The pore size distribution curve collects the impression from the sorption experiments and the visual methods.

The specific surface related to water adsorption was calculated in three different ways: From traditional BET-analysis, from V-t-pore analysis and from the calculation of the pore size distribution. The three results for each of the stones only differed slightly from each other. The BET-values are shown in Table 1.

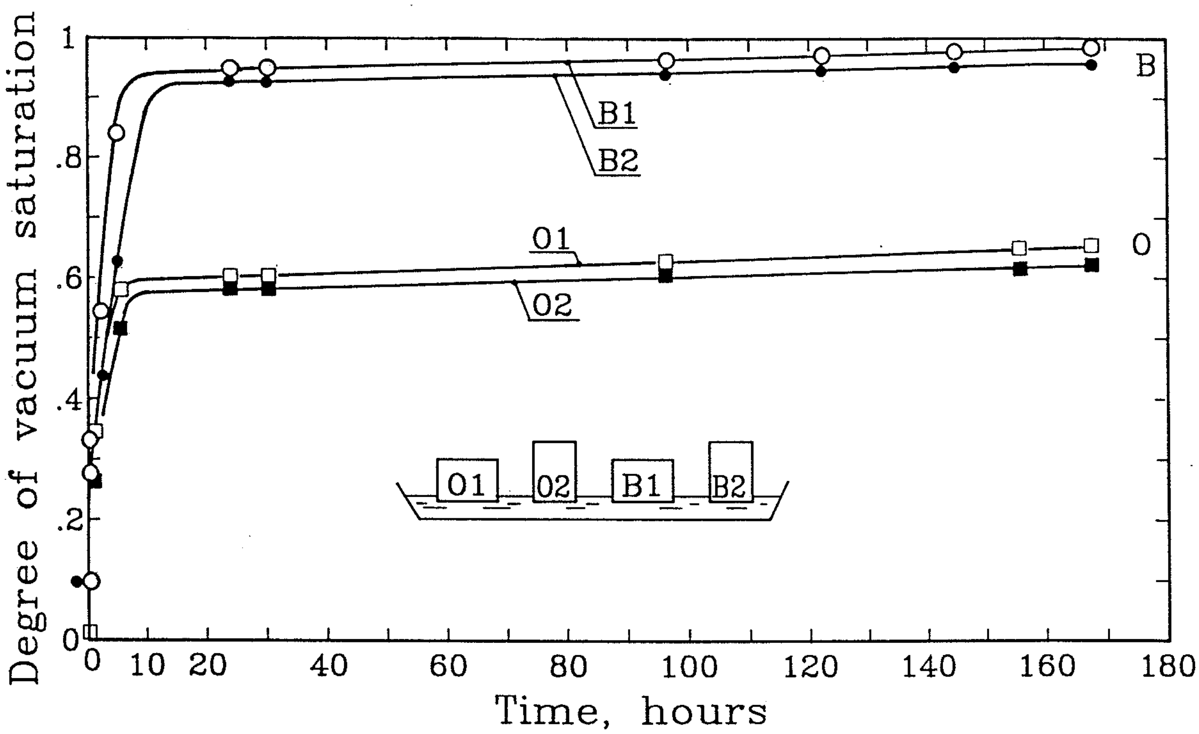


Figure 4. Capillary suction expressed as degree of vacuum saturation versus time. The water front reaches the top face of the specimens 3-12 hours after start of suction.

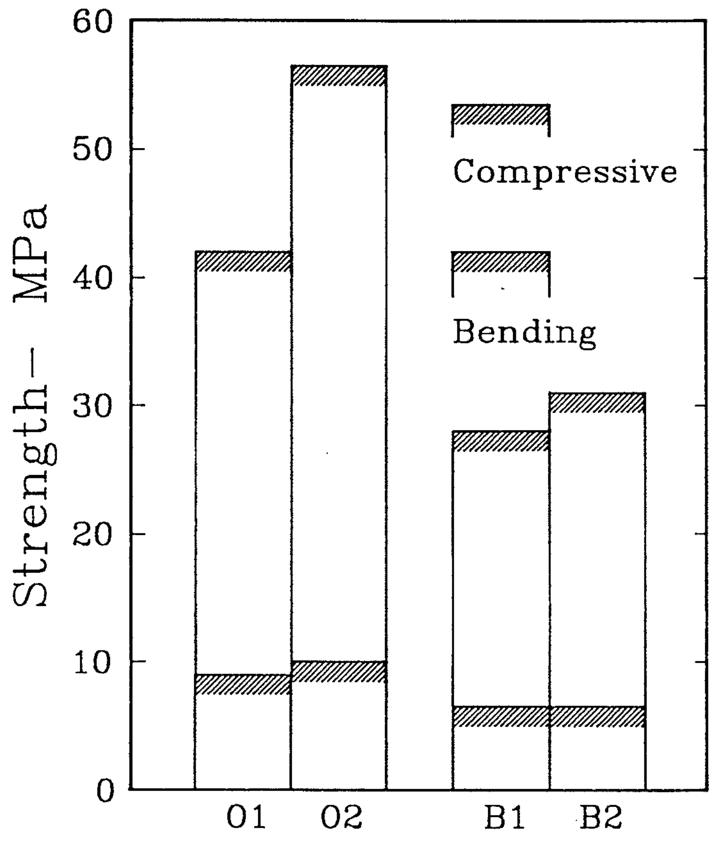


Figure 5. Strength values. Prisms with dimensions h x w x l = 35x50x150 mm were tested in bending and modified cube test.

Physical properties

Figure 4 gives the results from the capillary suction experiments. The figure shows the degree of saturation versus time in linear scale. (This form differs from previous habit in this country, which is to show mass per m^2 versus square root of time). The specimens are tested with the broad and the small face as suction area.

In a traditional plot with mass per m^3 versus square root of time it is seen, that in O the water front reaches the surface after 3,2 and 5,5 hours, and in B after 6,5 and 11,5 hours, which corresponds to the suction directions, the higher the specimens, the longer the time. From these plots the capillary suction coefficients have been read (Table 1).

The degree of saturation in O only reaches 0,65 and 0,62, whereas it in B exceed to 0,98 and 0,95. These two values are above the theoretical limit for frost resistancy of 0,91.

Figure 5 illustrates the strength values. O is the strongest material which also corresponds to the lower porosity of this materials.

The sound velocity values seems to coincide with the strength values, although the difference is not so large between the two materials as the difference between the compressive strengths.

Shrinkage due to loss of moisture from equilibrium at 80 %RH to equilibrium at 45 %RH were calculated according to a theoretical expression /4/. It is found that the shrinkage of O is only $4 \cdot 10^{-6}$, whereas B shows around $50 \cdot 10^{-6}$. This calculation supports the qualitative impression one can get from the sorption isotherms.

The sulphate resistance is tested according to DIN 52111. Dry specimens were exposed to suction of saturated Na_2SO_4-solution for at least 16 hours, drying at 105 °C in at least 8 hours and so on.

After 5 cycles B was totally disintegrated to a powder, whereas O only had rounded corners and week surfaces.

The acid resistance was examined. Small specimens were stored in HCl until equilibrium was reached. O was not infected, whereas 50% of B was dissolved.

Concluding remarks

The Obernkirchner stone is strong and has a very low sorption capacity. It is homogenous and consisting mainly of quarts. It has a pore size distribution with few small and many coarse pores, which determines that the water saturation after 168 hours is only about 65%. The sulphate resistance is good.

The Baumberger stone is mechanically weaker than the Obernkirchner. It is lime bounded. Its microstructure shows its origin with biological activity. Its sorption capacity is high and its pore size distribution is arranged so that its water saturation after 168 hours is 95-98%, which is above the theoretical limit of frost resistance. A theoretical calculation points on ten times higher shrinkage in this stone than in the Obernkirchner. It is neither sulphate nor acid resistant.

Our examinations confirms the reputation of the stones mentioned in the start of this report. The Obernkirchner stone is highly weather resistant, whereas the Baumberger stone only can be recommended for indoor use.

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Table 1. Measured values. For comparison the values from IBP are also shown.

Property	Unit.	Obernkirchner sandstone IBP	Obernkirchner sandstone O 1	Obernkirchner sandstone O 2	Baumberger sandstone IBP	Baumberger sandstone B 1	Baumberger sandstone B 2
Bulk dry density	kg/m^3	2147	2177	2204	1978	1990	1995
Density of solid phase	kg/m^3	2661	2597 x)	2601 x)	2686	2573 x)	2569 x)
Total porosity	m^3/m^3	0.193	-	-	0.264	-	-
Open porosity	m^3/m^3	-	0.162	0.152	-	0.226	0.223
Water content by mass: Free water saturation	kg/kg	$48\cdot10^{-3}$	$44\cdot10^{-3}$	$39\cdot10^{-3}$	$103\cdot10^{-3}$	$107\cdot10^{-3}$	$102\cdot10^{-3}$
Water content by mass: Vacuum water saturation	kg/kg	$66\cdot10^{-3}$	$48\cdot10^{-3}$	$43\cdot10^{-3}$	$108\cdot10^{-3}$	$111\cdot10^{-3}$	$107\cdot10^{-3}$
Water content by mass: Sorption at 80 %RH	kg/kg	$1.9\cdot10^{-3}$	$1.4\cdot10^{-3}$	$0.5\cdot10^{-3}$ +)	$15.3\cdot10^{-3}$	$18.5\cdot10^{-3}$	$1.0\cdot10^{-3}$ +)
Water content by mass: Sorption at 93 %RH	kg/kg	$4.3\cdot10^{-3}$	$2.5\cdot10^{-3}$	$0.5\cdot10^{-3}$ +)	$24.5\cdot10^{-3}$	$37.3\cdot10^{-3}$	$1.0\cdot10^{-3}$ +)
Specific surface (BET)	m^2/kg	-	$2.8\cdot10^3$		-	$20\cdot10^3$	
Water absorption coeff.	kg/m^2h	2.5-3.0	-	-	2.4-3.2	-	-
Capillary suction coefficient	$kg/m^2\cdot s^{\frac{1}{2}}$	-	$30\cdot10^{-3}$	$31\cdot10^{-3}$	-	$45\cdot10^{-3}$	$47\cdot10^{-3}$
Sound velocity	m/s	-	2680	2828	-	2632	2655
Bending strength	MPa	-	9.1	9.9	-	6.5	6.5
Compressive strength	MPa	-	42.4	56.6	-	28.2	31.5
Shrinkage, (80→45 %RH) calculated	m/m	-	$(4\cdot10^{-6})$		-	$(54\cdot10^{-6})$	
Sulphate resistance after DIN 52111, condition after 5 cycles		-	8% weight loss. Still solid under the week surfaces		-	Totally disintegrated	
HCl-diluted material	kg/kg	-	0		-	0.50	

x) Including closed pores

+) Adsorption values

( ) Values in brackets are theoretical

Table 2. Chemical composition according to an EDAX-examination

Element	O 1	B 2
Al	3.5 %	3.1 %
Si	93.4 %	43.6 %
Cl	1.3 %	0.6 %
K	0.7 %	1.5 %
Ca	0.1 %	48.3 %
Ti	0.6 %	-
Fe	0.4 %	2.9 %
Total	100.0 %	100.0 %