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MEASUREMENT OF THE GAS PERMEABILITY OF AUTOCLAVED AERATED CONCRETE IN CONJUNCTION WITH ITS PHYSICAL PROPERTIES

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ABSTRACT: The technique for determining the gas permeability of autoclaved aereted concret (AAC) which was developed here allows one to identify differences in the evolution of the porous structure caused by various manufacturing conditions. A comparison of permeability and compressive strength in relation to density illustrates a contradictory tendency on the part of these two physical properties i.e. as the raw density increases, compressive strength and permeability decline. Small cracks arising during the rising process result in decreased compressive strength in the direction of rising and an increased gas permeability perpendicular to that direction. This anisotropy in AAC can be more precisely illustrated by measuring the gas permeability than by determining the compressive strength, especially with lower classes of density.

Introduction

The aim of the study was to understand the anisotropy in AAC and the resultant directionally-dependent material characteristics. Citing DIN 51058 [1]: gas-permeability is related to the texture of the block, thus allowing inferences as to its consistency. Instruments and procedures for measuring gas permeability are described in [1, 2, 3, 4, 5, 6, 7].

Appropriate equipment for measuring gas-permeability and thus indirectly characterizing the pore structure of AAC was developed and constructed. In addition, various physical factors influencing gas permeability were worked out. Further, it was demonstrated how the pore structure is influenced by different molding conditions during the manufacture of AAC.

Fundamental Concepts

The problem of anisotropy in ready-to-assemble building components becomes apparent during the manufacturing process [8]:

The raw materials are quartz sand, a binding agent (lime and cement), anhydrite or gypsum, a rising agent (aluminum powder or paste) and water. The raw materials are finely ground, measured out, combined to a watery suspension in a mixer and poured into molds. As heat develops, the water dissolves the lime. The aluminum reacts in compound with the alkaline water, setting hydrogen gas free and causing the mixture to rise and fill out the mold. This is how the pores are formed in AAC. However, a certain direction is favored and this is called the direction of rising. The firm raw block (the "cake") is removed from the mold and then cut. The cut block is then sent on special grates to the autoclave for steam curing, where it is exposed to saturated steam at 190°C and 12 bars of pressure. The AAC then has the desired characteristics.

The type, the size and the size distribution of the pores are chiefly responsible for air permeability and not the pore volume, as might be expected [9]. With respect to the various types of pores, only those that are continuous and permit gases to flow through the entire block are of significance for gas permeability and evaluating the porosity of AAC.

With a total porosity of 75 to 90 Vol.% i.e. density classes of 0.6 to 0.3 kg/dm^3, the volume percentage of macropores (with a diameter of more than 10^{-4}m) being from 50 to 75 Vol.% and the volume percentage of micropores (with dimensions of 10^{-7} to 10^{-4}) being from 25 to 15 Vol.%, were tabulated [10, 11, 12].

Research into the porous structure has shown that when the gas permeability of AAC is measured at atmospheric pressure using air as the permeating medium, laminar flow (95% of the flow per mass) predominates. Only 5 % occurs via mixed transport i.e. laminar and Knudsen-flow. Pure molecular flow does not occur at all [13]. Using the Law of Hagen-Poiseuille for the flow of gaseous media through a porous body, taking into account the gas' compressibility, one obtains the following equation for the specific gas permeability for laminar flow [2]:

$$D_s = \frac{\eta \cdot l}{A} \cdot \frac{V}{t} \cdot \frac{p}{p_E - p_A} \cdot \frac{2}{p_E + p_A} = \frac{r^2}{8} \qquad (1)$$

where D_s specific gas permeability [nPerm = 10^{-13}m^2]
η the dynamic viscosity of the gas [Pa · s]
l the length or the thickness of the porous body permeated [m]
A sectional area of the porous body permeated [m^2]
V gas volume [m^3]
t test duration [s]
p pressure at which gas volume was determined [Pa]
p_E entry pressure of the gas [Pa]
p_A exit pressure of the gas [Pa]
r pore size (capillary radius) [m]

Since according to equation 1 the specific gas permeability depends solely on the porosity of the material, it represents a material dimension.

Experimental Investigations

Measurement Technique

In the method used, a sample sealed in a silicon-rubber ring was placed in a testing chamber ("vacuum bell") sealed on one side, over a vacuum opening.

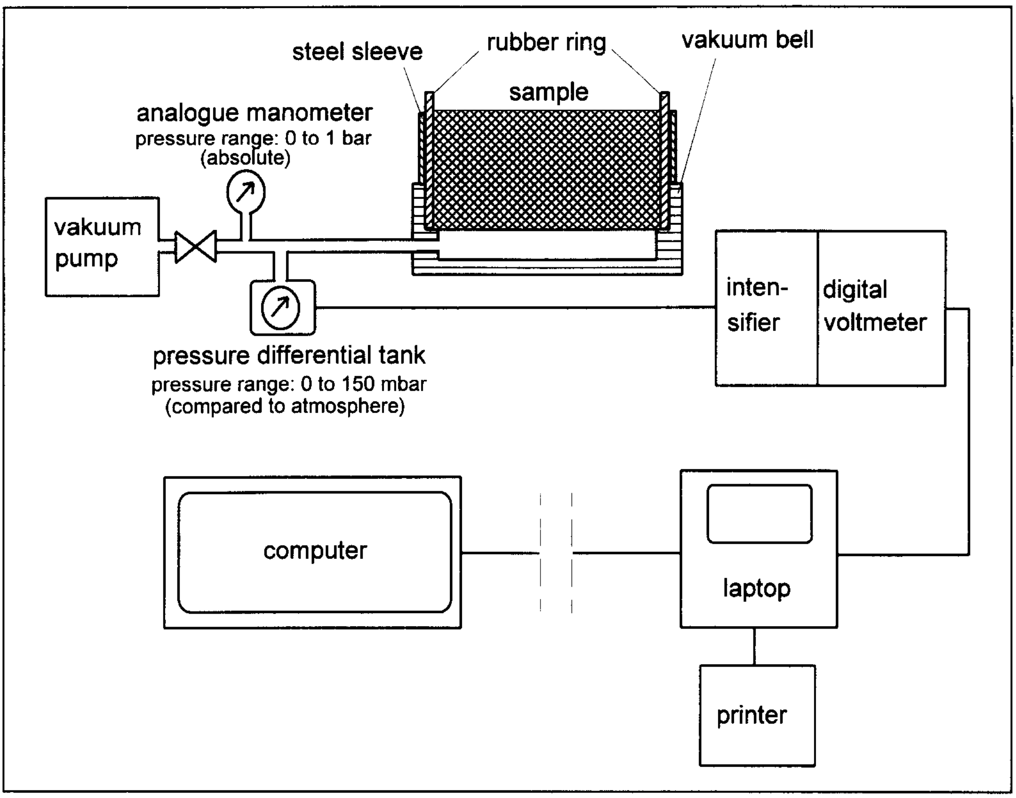

FIG. 1
Functional diagram of device for measuring gas permeability

Low pressure results on one side of the sample by switching on a vacuum pump and opening a valve. This can then be read as approximately the absolute pressure with an analogue manometer. After the valve is closed between the "vacuum bell" and the vacuum pump, the rise in pressure as compared to atmospheric pressure can be quantified using an inductive measuring system consisting of a differential pressure sensor with a built-in intensifier, thus allowing for the measurement of pressures from 800 to 15000 Pa below atmospheric pressure. An increase in pressure is only possible if air from above flows through the AAC sample into the interior of the "vacuum bell". Consequently, the more permeable the AAC, the faster the pressure will rise.

The increase in pressure measured against time can be transmitted to a laptop with the aid of a digital voltameter via a data-collection program and stored on 3.5" floppy discs. The stored data are then processed in a computer, thus assuring access to the values and results at any time.

Production of the Samples

The test blocks were taken either from a normal production run at Hebel AG or were produced especially in the laboratory. Cylindrical samples having a diameter of 150 mm or a thickness of 60 mm were sawed out.

Five samples were taken per production series from various heights in such a way that the flow during permeability measurement occurred in the direction of rising. An additional five samples were sawed out so that flow occurred perpendicular to the direction of rising. Five density classes were chosen (G2/0.35, G2/0.4, G2/0.5, G4/0.6, G6/0.7), produced under the same conditions of molding and curing.

For the samples produced in the laboratory, the porous structure was varied by applying different molding conditions. Three manufacturing parameters were varied: the type of aluminum, the molding temperature and the lime. Due to the small molds used in producing samples in the laboratory, only three sections each could be taken for measuring flow in the direction of, and perpendicular to, the direction of rising.

Results

For AAC of the density classes G2/0.35 to G6/0.7, decreasing permeability coefficients of around 5.5 nPerm to 0.1 nPerm were obtained.

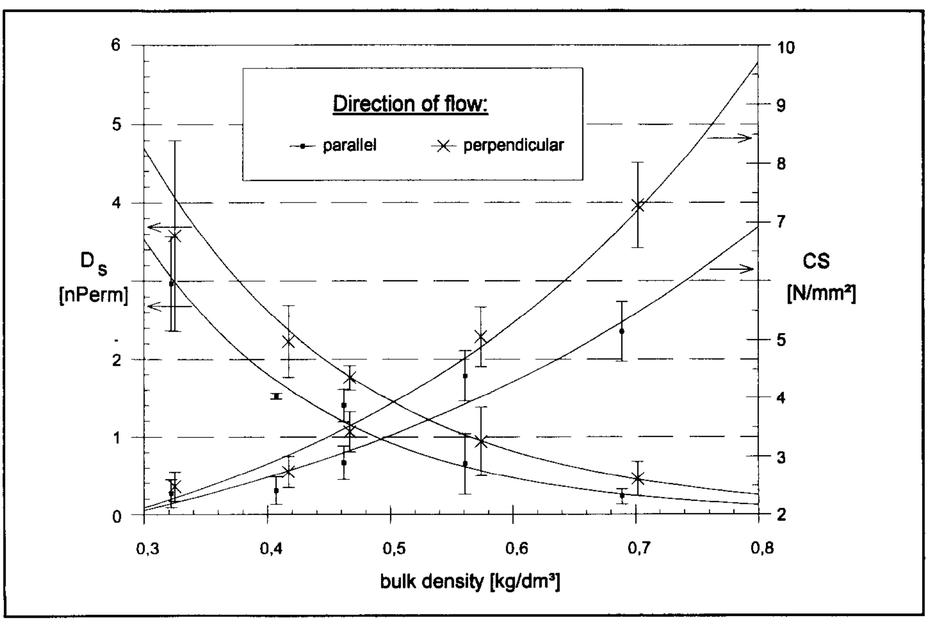

FIG. 2

Gas permeability and compressive strength for both flow directions

Gas permeability perpendicular to the direction of rising is higher than parallel to that direction. Viewed absolutely, this difference diminishes with higher density classes. Compressive strength values likewise reveal increased compressive strength perpendicular to the direction of rising. The density dependence exhibits a contrary tendency for these two physical properties, however (FIG. 2). This is due to small cracks (FIG. 3) originating during the rising process, which are responsible for decreased compressive strength in the direction of rising and for increased gas permeability perpendicular to that direction.

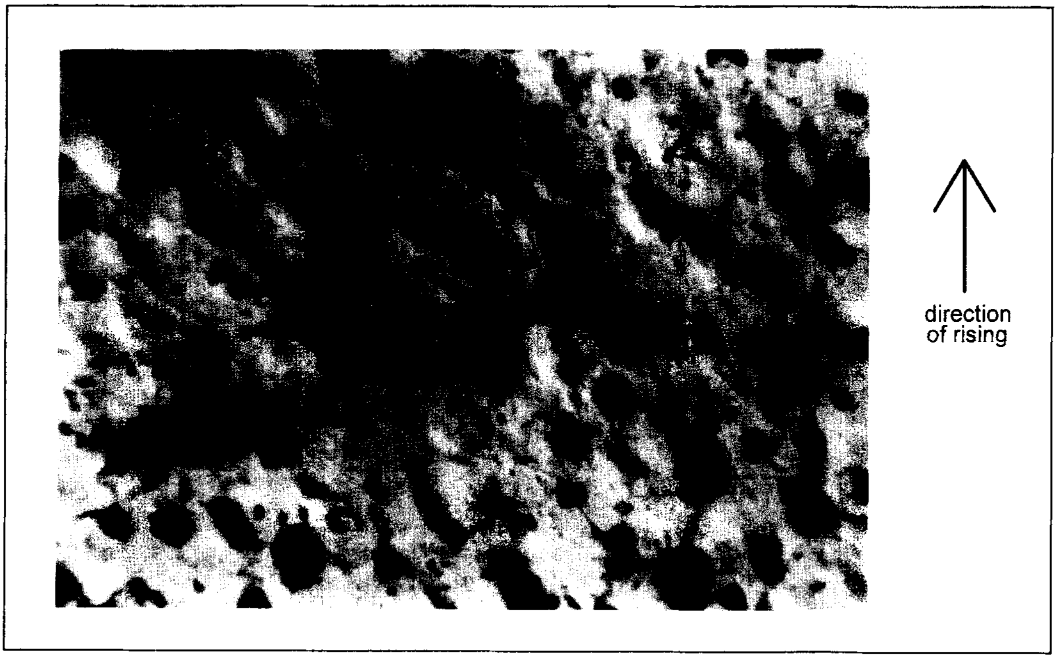

FIG. 3
Crack perpendicular to the direction of rising

The permeability varied, depending on the height from which the samples were taken i.e. the values observed for the lower core samples were lower than the ones taken from further above. This was due to the non-homogenous nature of the AAC cake caused by the different densities at different heights.

The influence of the sample's moisture on gas permeability can be ignored in the critical range of 2 to 15 mass%.

Both raising the molding temperature and using an "aggressive" aluminum powder instead of a "slow" one increase permeability. The concomitant reduction in compressive strength is however not as marked as the increase in permeability might lead one to believe.

Permeability decreases as calcium hydrate is gradually substituted for lime. No statement can be made as to compressive strength in connection with this factor.

An average overall error-rate of 19 % occurs when using the method of measurement developed in connection with this work to determine specific gas permeability.
The predictive value and reproducibility of the results have been verified by an independent outside analysis of several samples at the ETH in Zürich. In addition, the variable parameters encountered while carrying out the measurements were checked.

Overview

Due to the variation in the values measured, only a qualitative and not a quantitative connection can be made between permeability and compressive strength as a significant physical property of AAC. Measurements of gas permeability at the lower classes of density possess a higher sensitivity to anisotropy in AAC than the determination of compressive strength. This is probably caused by the considerable structural disturbances due to the high porosity (up to 90 Vol.%) which would affect compressive strength even without the small directional cracks.

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